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IRON AND STEEL INSTITUTE

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PREFACE.

THE present volume contains eleven papers presented at the Autumn Meeting held in Sheffield on Tuesday, November 12th, 1940; of these, three were presented under the auspices of the Joint Research Committees of the Institute and the British Iron and Steel Federation, and one is a record of a research carried out with the aid of a grant from the Andrew Carnegie Research Fund. The discussions and correspondence to which these gave rise are also included; the authors' replies are appended, except in two cases where the absence of the authors overseas has made it impossible to include them— they will be printed in the No. I. volume of the *Journal* for 1941. In addition, the authors' replies to the discussion on two papers included in the No. I. volume for the year, which had not been received in time for inclusion in that volume, will be found in the present book.

The foregoing papers, together with the Minutes of Proceedings of the Meeting and biographical notes on deceased Members are included in Section I. of this *Journal*. Section II. is devoted to a survey of the literature on the manufacture and properties of iron and steel, and kindred subjects, and consists of a collection of abstracts of articles from the Transactions and Proceedings of scientific societies and from the technical press. This Section also contains reviews of recent books and bibliographies of literature dealing with the manufacture and properties of iron and steel. The matter included in this Section has already appeared in the *Bulletin of the Iron and Steel Institute*, which is issued monthly.

In front of the title-page is inserted a list of the British Standardised Steel Samples issued jointly by The Iron and Steel Institute and the National Physical Laboratory, showing where and on what terms the samples are available. Proposal forms for Membership and Associateship and also for Joint Membership of this Institute and the Institute of Metals will likewise be found in the same place.

4, GROSVENOR GARDENS,
        LONDON, S.W.1.
    February, 1941.

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ABBREVIATIONS USED IN TEXT.

Å.	Ångström unit(s).	kg.	kilogramme(s).
A.C.	air-cooled; alternating current.	kg.cal.	kilogramme-calory; -calories.
A.H.	air-hardened.	kg.m.	kilogramme-metre(s).
amp.	ampère(s).	km.	kilometre(s).
amp.hr.	ampère-hour(s).	kVA.	kilovolt-ampère(s).
atm.	atmosphere(s) (pressure).	kW.	kilowatt(s).
Bé.	Baumé (scale).	kWh.	kilowatt-hour(s).
b.h.p.	brake horse-power.	lb.	pound(s).
B.o.T.	Board of Trade.	L.F.	low-frequency.
B.Th.U.	British thermal unit(s).	m.	metre(s).
C.	centigrade (scale).	m.amp.	milliampère(s).
cal.	calory; calories.	mV.	millivolt(s).
c.c.	cubic centimetre(s).	max.	maximum.
c.d.	current density.	mg.	milligramme(s).
c.g.s.	centimetre-gramme-second unit(s).	min.	minimum; minute(s).
		ml.	millilitre(s).
cm.	centimetre(s).	mm.	millimetre(s).
coeff.	coefficient.	m.m.f.	magnetomotive force.
const.	constant(s).	N.	normal (solution).
c.p.	candle-power.	N.T.P.	normal temperature and pressure.
cu.	cubic.		
cwt.	hundredweight(s).	O.H.	open-hearth; oil-hardened.
D.C.	direct current.	O.Q.	oil-quenched.
dia.	diameter(s).	oz.	ounce(s).
dm.	decimetre(s).	p.d.	potential difference.
e.m.f.	electromotive force.	pH	hydrogen-ion concentration.
F.	Fahrenheit (scale).		
ft.	foot; feet.	r.p.m.	revolutions per minute.
ft.lb.	foot-pound(s).	sec.	second(s).
g.	gramme(s).	sp. gr.	specific gravity.
gal.	gallon(s).	sq.	square.
H.F.	high-frequency.	T.	tempered.
h.p.	horse-power.	temp.	temperature.
h.p.hr.	horse-power-hour(s).	V.	volt(s).
hr.	hour(s).	VA.	volt-ampère(s).
in.	inch; inches.	Wh.	watt-hour(s).
in.lb.	inch-pound(s).	W.Q.	water-quenched.
K.	absolute temperature (Kelvin scale).	yd.	yard(s).
		°	degree(s).

SECTION I.

MINUTES OF PROCEEDINGS AND PAPERS OF THE IRON AND STEEL INSTITUTE.

AUTUMN MEETING

1940

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MINUTES OF PROCEEDINGS,
PAPERS AND DISCUSSIONS

AT THE

AUTUMN MEETING IN SHEFFIELD, 1940.

THE AUTUMN MEETING OF THE IRON AND STEEL INSTITUTE was held in Sheffield, on Tuesday, November 12th, 1940 ; Mr. John Craig, C.B.E. (President), was in the Chair. By arrangement with the Presidents and Councils of the Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association, it was a Joint Meeting with these Societies, and a large number of their Members were present.

A small Committee of Arrangements, under the Chairmanship of Dr. W. H. Hatfield, F.R.S. (Vice-President), had been formed, and the Council wish to take this opportunity to thank them for their assistance.

The Meeting took place at the Grand Hotel. The proceedings opened with a Luncheon, after which two Sessions for the discussion of papers were held, with a short interval for tea.

LUNCHEON.

The Luncheon, held at the Grand Hotel, was attended by about 275 Members and Guests. The PRESIDENT (Mr. John Craig, C.B.E.) presided. Among the Guests were the Deputy Lord Mayor of Sheffield (Alderman J. A. Longden, J.P.), the President of the Sheffield Society of Engineers and Metallurgists (Mr. A. Roebuck) and the President of the Sheffield Metallurgical Association (Mr. H. H. L. Lockley) ; the Master Cutler (Mr. W. Wilkinson Wood) was unable to attend the Luncheon, but was present for a short while towards the end.

After the Loyal Toast had been honoured the DEPUTY LORD MAYOR (Alderman J. A. Longden, J.P.) proposed the Toast of

The Iron and Steel Institute and Kindred Societies,

in particular, the Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association. He said that he could have understood being asked to propose the toast as Lord Mayor

but he was rather puzzled to know whether he was intended to do
so as Deputy Lord Mayor. The Secretary of the Institute, how-
ever, had helped him out of the difficulty by saying : " We know
you will not be Lord Mayor," and he had then felt a little more
comfortable ! He was reminded of a certain newly-elected Lord
Mayor who, coming out of the town hall and nodding to everyone
he met because of the importance of his position, was accosted by
one man who said to him : " Excuse me, sir, but are you the gentle-
man whose picture I saw in the paper the other day ? "   " Well,"
replied the Lord Mayor, " I have been very prominent in the
Press lately," and the man thereupon said : " I thought so. I
recognised your portrait. I should like to tell you that I tried that
remedy for rheumatism and it failed." (*Laughter.*) To-day he
felt somewhat like that Lord Mayor.

During his year of office he had tried to avoid big men, but
he had often been thrown amongst men of big physique and great
ability ; it seemed to be his fate to get between them, and he then
looked like an errand boy. (*Laughter.*) On the present occasion
again he was between two big men in physical stature and in
mental capacity and importance, and he felt a little diffident in
speaking. He remembered a professor addressing a meeting of
students and telling them about corpuscles. He said : " You all
know what the inside of a corpuscle is," and the Chairman of the
meeting said : " Well, of course, some of us know, but you had
better explain about it for the benefit of those who have never
been inside one." (*Laughter.*) He felt like that himself, and when
Dr. Hatfield told him that the President controlled a firm with an
annual output of $1\frac{1}{2}$ million tons of steel he felt less important
than ever and rather wished that Dr. Hatfield had postponed
giving him that information until after he had made his speech.
He felt very insignificant and helpless amongst so many technicians.

He had much pleasure in proposing the toast, because he knew
the importance of the iron and steel industry, which was now
recognised. He had said before and he wished to repeat on the
present occasion that those connected with the heavy industries
sought by association in such organisations as The Iron and Steel
Institute to find the best. (*Hear, hear.*)

He thought that industrialists in Britain were too generous to
their customers. He had visited a firm that day, and before he
could get into the inquiry office he had had to ring a bell ; that
was quite right and proper, and that practice should obtain after
the war as well as during it. People had come to him and said : " I
have a difficulty in my business ; if I could get over it I could
compete with anybody. I just want to get inside a firm to see
the name on a machine, and I could then beat my competitors."
They managed to get inside and to see what they wanted to see,
because they were the firm's customers. Such firms had taken
them inside and taught them their business, so that they could be

their competitors; the firms had been too generous and were now paying for their generosity. He did not think that had been a good thing.

The Iron and Steel Institute and kindred bodies were of great value and benefit to industry, and he would urge them not to cease their labours but to continue to carry out experiments and investigations which would make this country and the Empire greater than ever. Workmen were of no use without technicians. Workmen used to say that they were the producers, but he thought it was now realised that the technicians or black-coated workers must be united with the workmen if this nation was to stand against its competitors.

He wished The Iron and Steel Institute every success and had much pleasure in coupling with the toast the name of the President, Mr. John Craig.

The PRESIDENT (Mr. John Craig, C.B.E.), in responding, said that he found himself in complete agreement with the sentiments expressed by the Deputy Lord Mayor and was sure that they would be endorsed by everyone present.

The Institute had had considerable difficulty in arranging the Meeting which it was holding that day. The times were not opportune for social gatherings, although the need for social gatherings was as great as ever. However, it had been felt that, if there were any place in Great Britain where the Institute could foregather in the present circumstances, that place was Sheffield, and that in Sheffield the Members of the Institute could hold a joint meeting with members of two of the societies which still actively pursued their work, namely, the Sheffield Metallurgical Association and the Sheffield Society of Engineers and Metallurgists. The present Meeting had been made possible by the happy co-operation of those two societies with The Iron and Steel Institute. Without that, the Institute could scarcely have hoped to hold such a great gathering, and it was particularly indebted to Dr. Hatfield, its senior Vice-President in Sheffield, for acting as Chairman of the Committee of Arrangements. It would have been a pity if, at a time when the steel industry was so much in the minds of the public, the Institute had had to forgo its autumn gathering.

The Deputy Lord Mayor had said that the iron and steel industry was now recognised to be one of great importance, and the Members of the Institute were glad of that, although they were sorry for the circumstances which had brought their industry into such prominence. They hoped, however, that the lesson of this time would be learned by the country as a whole. There was no time in the nation's history when the iron and steel industry had not been of importance. There were times when it had been neglected, but it had never been neglected without serious loss to the country, and if the country had taken a larger outlook and a more generous

attitude towards the industry it might have been better equipped than it had been in September, 1939. (*Hear, hear.*) It was quite true that the steel trade could do without war—its happiest days had been without war—but it was certain that war could not do without the steel trade, and the steel industry was therefore faced with the fact that it was in the front rank of importance in the great crisis with which the country was confronted to-day.

He had been glad to hear the sentiments expressed by Alderman Longden, because there had been a time, as he had indicated once before to the Institute, when the technician and the scientist were regarded as having no great part to play, but now that there was a shortage of certain things it was recognised that the scientist had helped in a remarkable way and had time and again submitted alternatives which had been effective and successful. Without the scientist he did not think that the steel trade could be in the position which it occupied to-day, and he therefore thought that the Institute, because of its great principle of fostering the development of technical education and scientific research, had proved abundantly that if there were any industry which needed the scientist it was the steel trade. Greater demands were now being made upon the steel industry than had been made upon it at any previous time in its history, and he thought it could claim an honoured place among the country's great industries for what it had done, for what it was seeking to do to-day and for what he believed it would do in the future. He did not think the results which could arise from the scientific knowledge that was available for use in the steel industry had been exhausted. He hoped that the Institute would receive the support of all in the industry, and that all who were associated with the industry would feel that it was through the Iron and Steel Institute that they could best develop the future success of their industry.

He thanked the Deputy Lord Mayor for his generous reference to the Institute, and he also wished to thank the two kindred societies in Sheffield for co-operating with the Institute in making the present Meeting a successful one. The papers to be submitted might be looked upon in times to come as historic, and the Meeting might be looked upon as a memorable one in the development of the iron and steel industry. Finally, he wished again to thank Dr. Hatfield for acting as Chairman of the Committee of Arrangements.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), in proposing the toast of

The President,

said that everyone present knew the great enterprise which Mr. Craig controlled and recognised that it must have been difficult for him to come from Scotland to attend the Meeting that day.

He was glad that Mr. Craig had been able to do so, because he thought that, although it was not possible to say much on the subject at the present moment, after the war it would be recognised that The Iron and Steel Institute, particularly through its various scientific and technical committees, had done well during the present critical period. On behalf of his scientific and technical colleagues in the industry, he wished to thank Mr. Craig for coming to the Meeting that day. They felt, of course, that science and technology must be carried on in spite of the war. The war might last two years or five years or even ten years, but it was impossible to conceive the lapse of a period of years in the evolution of the science and technology which served the iron and steel industry.

The other day he had been waiting for a Member of the Institute in the library at his research laboratory; he had gone to the book-case to find a book to read while waiting, and he had taken down the first volume of the *Journal of The Iron and Steel Institute*. He recommended others to read it, as it was very entertaining. He found that in the year in question, 1869, Mr. Menelaus had said " In England we are met with the difficulty of frequently having to change the section in rolling; " that state of affairs had con-tinued for seventy-one years. (*Laughter.*) One of the major committees operating in Britain to-day, however, was doing a great deal to alter that, to the advantage of the country.

The PRESIDENT briefly thanked Dr. Hatfield for his kind remarks. He added that the Master Cutler had just entered the room and he was sure those present would wish him to say a few words.

The MASTER CUTLER (Mr. W. Wilkinson Wood) expressed his regret that he had been unable to accept the invitation to attend the Luncheon and also that, owing to the difficult circumstances of the times, it had not been possible for the Cutlers' Company to offer the hospitality to the Institute that it would have offered in normal times.

The last occasion when he had seen The Iron and Steel Institute *en masse* had been at Krupp's works in Essen three or four years ago, when they had spent a very pleasant evening at the Villa Hügel. It was sad to contrast those days with the state of affairs at the present time, but he thought some of those who had visited Krupp's works on the occasion to which he referred had then believed that war would come.

AFTERNOON SESSION.

The PRESIDENT (Mr. John Craig, C.B.E.) opened the Meeting at 2.45 P.M. The Minutes of the last General Meeting, held in London on May 2nd and 3rd, 1940, were taken as read, and were confirmed and signed.

Obituary.

The PRESIDENT said that he had a sad duty to perform in referring to the death of two distinguished members of the Institute, Sir Harold Carpenter and Sir Robert Hadfield. Both had been well known to many Members of the Institute, and he knew that the sadness felt by the Members of the Council at the death of these two colleagues would be shared by all the Members. Both had been Fellows of the Royal Society and men of international reputation in their different spheres.

Sir Robert Hadfield needed no words of his in the city of Sheffield ; the Members grieved for a great citizen who had been also a great industrialist and discoverer, a man whose name would be remembered as long as Sheffield made steel.

Sir Harold Carpenter had been acknowledged to be the respected head of the metallurgical profession of this country. He had been a careful and accurate investigator, a brilliant teacher and a most lovable man. It was perhaps not so widely known that his services had been constantly called on by Government authorities when advice on metallurgical problems was required.

Sir Harold and Sir Robert had both served as President of the Institute and had had the interests of the Institute at heart. Like many conspicuously busy men, they had found time to be the most regular attendants at meetings of the Council and at the Institute's discussions. They had rendered great service to the Institute ; the present Members were their debtors and future Members would also be their debtors.

He was sure that all present would wish their sincere expressions of regret and sympathy to be sent to Lady Hadfield and to Lady Carpenter, and he would arrange for that to be done.

At the request of the President, the members stood in silence for a few moments.

Ballot for the Election of New Members and Associates.

Mr. G. A. V. RUSSELL (Sheffield) and Mr. W. E. BENBOW (London) were appointed scrutineers of the ballot for the election of new Members and Associates, and later they reported that the following one hundred and eleven Members and thirty-six Associates had been elected :

MEMBERS.

ADAMS, JAMES	.	Manchester.
ALLAN, GEORGE HAY	.	Glasgow.
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ARMITAGE, WILLIAM	.	Manchester.

ARNOLD, THOMAS HENRY . . Sheffield.
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ATKINS, MALCOLM, B.Sc. . . Sheffield.
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BIANCHI, PERCIVAL . . . London.
BLECKLY, REGINALD SANDERSON . Warrington.
BOALER, ERNST . . . Corby, Northants.
BOOTH, JAMES C. . . . Manchester.
BRAND, HARRY MARK . . London.
BRIDDON, W. . . . . Sheffield.
BROUGH, EDWARD . . . Walsall, Staffs.
BURNLEY, HARRY . . . Sheffield.
CAMERON, PETER . . . Watford, Herts.
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COLDWELL, THOMAS CRAIG . . Glasgow.
COLE, T. H. . . . . Sheffield.
CONWAY, CYRIL GORDON, B.Sc.
  (Physics) (Lon.) . . . Birmingham.
COOPER, W. . . . . Sheffield.
CROSSLEY, ARNOLD . . . Sheffield.
DART, JOHN R. . . . Wolverhampton.
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DAWSON, HENRY THOMAS . . Corby, Northants.
DAYSON, JOHN CARLTON . . Manchester
DEAN, N. . . . . Wolverhampton.
DUNHAM, HENRY . . . Sheffield.
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      Africa.
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FALLON, WILLIAM T. . . Wolverhampton.
FAWKES, ALBERT LESLIE . . London.
FLEMING, JAMES LIONEL . . Sheffield.
FRASER, NOEL G. . . . Port Kembla, N.S.W.,
      Australia.
FROST, S. . . . . Sheffield.
GARTSIDE, FREDERICK . . Sheffield.
GIFFEN, EDMUND, D.Sc., Ph.D.,
  M.I.Mech.E. . . . Brentford, Middlesex.
GOLD, JOHN HENRY . . . Sheffield.
GOLDSBROUGH, WALTER . . Manchester.
GORDON, ROBERT . . . Bothwell, Lanarkshire.
HADDEN, RODERICK McKENZIE . Glasgow.
HARRIS, B. M. . . . Kettering, Northants.
HARRISON, JOHN METCALFE . . Manchester.
HARTLAND, F. E. . . . Wolverhampton.
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HOWELL, DUNCAN . . . Davyhulme, Lancs.
HUNTER, GILBERT ALEXANDER . . Corby, Northants.
HUTCHISON, GEORGE J. B. . . Corby, Northants.
HUTTON, WILLIAM GRAHAM . . Glasgow.
IRVINE, JOHN . . . . Corby, Northants.

JACK, ALEXANDER CAMERON . .	Corby, Northants.
JARVIS, SYDNEY EWART . . .	Sheffield.
JAY, ALFRED HART, B.Sc. (Hons. Physics), M.Sc., Ph.D., F.Inst.P. .	Sheffield.
JONES, LEONARD	Corby, Northants.
JONES, Sir WALTER BENTON, Bt. .	Sheffield.
KEEN, WILLIE	Sheffield.
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McMINN, ERNEST	London.
McNAIR, CHARLES, Assoc. Met. (Sheffield)	Sheffield.
McSKIMMINGS, WILLIAM, jun. . .	Corby, Northants.
MARSH, DENNIS WILLIAM . .	Corby, Northants.
MASSON, CHARLES GEORGE . .	Corby, Northants.
MILES, RALPH ELSTON . . .	Manchester.
MOORE, S. O.	Wolverhampton.
MOTTERSHAW, F. J. . . .	Sheffield.
MUNYARD, MATTHEW HENRY, A.M.I.Mech.E.	Market Harborough,Leics.
MUXLOW, HENRY LESLIE . .	Kettering, Northants.
NICHOLLS, WILLIAM, B.Sc.(Hons.) .	Birmingham.
OTLEY, RICHARD	London.
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STEWART, GAVIN BURTON . .	London.
SURTEES, WILLIAM . . .	Manchester.
TAYLOR, FREDERICK WILLIAM .	Sheffield.
THOMAS, REGINALD VICTOR .	Kettering, Northants.
TILL, JOHN W. . . .	Bilston, Staffs.
TRISE, HERBERT REGINALD . .	Portsmouth.

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   F.C.S.   .   .   .   .   .   Cheam, Surrey.
WHITAKER, PAUL   .   .   .   Market Harborough, Leics.
WHITELEY, CECIL   .   .   .   Birmingham.
WHITING, TOM WILTON   .   .   Coventry.
WILLETTS, FRED   .   .   .   Cradley, Staffs.
WILLIS, W. H.   .   .   .   Wolverhampton.
WILSON, WILLIAM WALTON, M.Met. .   Sale, Cheshire.

ASSOCIATES.

ANDERSON, RONALD OWEN   .   .   Sheffield.
BATE, NIGEL H.   .   .   .   .   Dudley, Worcs.
BENNETT, BENJAMIN   .   .   .   Sheffield.
BLACKWELL, WILLIAM T. .   .   .   Wolverhampton.
CAMPBELL, CHARLES STANLEY .   .   South Shields, Durham.
CHARLESWORTH, PHILIP   .   .   .   Scunthorpe, Lincs.
CREEVY, JOSEPH ALOYSIUS   .   .   Sharon, Pa., U.S.A.
DAVIES, DAVID JOHN   .   .   .   Llandyssul, Cardiganshire.
FITZPATRICK, RALPH N. .   .   .   Philadelphia, Pa., U.S.A.
GREENFIELD, STANLEY   .   .   .   Walsall, Staffs.
HARDY, HAROLD KENYON   .   .   Banbury, Oxfordshire.
HOLWAY, W. G., B.Sc.   .   .   .   Swansea.
HOPKINS, BERNARR EUGEN,
   B.Sc.(Hons.)   .   .   .   .   Birmingham.
HULL, JAMES .   .   .   .   Sheffield.
JARVIS, FRANK WOOLGAR,
   B.Sc.(Hons.)   .   .   .   Sheffield.
JOHNSON, JAMES STRETTON   .   .   Darlaston.
LEDER, PETER LEONARD JOHN .   .   Birmingham.
LLOYD, EDWARD H.   .   .   .   Birmingham.
LUCE, GEORGE   .   .   .   Wolverhampton.
LUNN, REGINALD GORDON   .   .   Sheffield.
MARSHALL, WILLIAM KING BATES   .   London.
MAYER, GEORGE, B.Sc.(Hons. Met.) .   Birmingham.
MOORE, E. J. .   .   .   .   Northwich.
MUIR, SAMUEL   .   .   .   Corby, Northants.
OWEN, LESLIE G.   .   .   .   Bilston, Staffs.
RAMAN, S. VENKETA, B.Sc.(Met.)   .   Hourah District, India.
SHOWELL, GEOFFREY DUGARD, B.Sc.   Newport, Mon.
SMITH, DEREK L.   .   .   .   Bilston, Staffs.
STANLEY, L. ROY   .   .   .   Wednesbury, Staffs.
STONE, ERIC HAYES FREDERICK   .   Birmingham.
STRUDWICKE, ALEXANDER W. .   .   Wednesbury, Staffs.
THEXTON, JOHN   .   .   .   Sheffield.
TURPIN, WILFRID SURTEES,
   B.Sc.(Met.) .   .   .   .   Manchester.
UNWIN, DAVID JAMES DOUGLAS   .   Sheffield.
VICKERY, RONALD CHARLES, B.Sc.   .   Corby, Northants.
WILLMOTT, PETER LLOYD   .   .   Raunds, Northants.

Members of Council Retiring in 1941.

The SECRETARY (Mr. K. Headlam-Morley), in accordance with Bye-Law 10, announced the names of the Members of Council retiring in rotation at the next Annual Meeting, as follows :

Vice-Presidents : Mr. Arthur Dorman; Mr. J. S. Hollings; Mr. C. E. Lloyd.

Members of Council : Captain H. Leighton Davies; Mr. I. F. L. Elliot; Principal C. A. Edwards, F.R.S.; Mr. E. F. Law; The Hon. R. G. Lyttelton.

All these gentlemen were eligible for re-election.

The Ablett Prize, 1941.

(*Alteration of Conditions of Award.*)

The PRESIDENT reminded Members that the Council had accepted an offer from Captain C. A. ABLETT, O.B.E., B.Sc., M.Inst.C.E., to renew his Prize of £50 for a paper on a subject connected with engineering in iron or steel works. By agreement between Captain Ablett and the Council, the conditions governing the award of the Prize had been altered, and were now as follows :

(*a*) Competing papers shall deal with a subject connected with engineering in iron or steel works.

(*b*) Competing authors shall be British subjects employed in the iron and steel industries of Great Britain or the British Empire. The competition shall be open to both Members and Non-Members of The Iron and Steel Institute.

(*c*) The decision of the Council of The Iron and Steel Institute shall be final as to whether a paper is eligible and on all matters arising out of the award of the Prize.

Competing papers should be marked " Ablett Prize Paper " and sent to the Secretary of the Institute not later than May 31st, 1941. The successful paper would be presented at the May Meeting and printed in the Institute's *Journal.*

Complete List of Papers Presented at the Autumn Meeting in Sheffield,
1940.

C. A. EDWARDS, F.R.S., D. L. PHILLIPS and H. N. JONES : " The Influence of Some Special Elements upon the Strain-Ageing and Yield-Point Characteristics of Low-Carbon Steels."

W. H. HATFIELD, F.R.S., and G. W. GILES : " Non-Metallic Inclusions in Steel. Quantitative Evaluation.—Part I." (Paper No. 3/1940 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Inclusions Sub-Committee)).

E. A. JENKINSON : " The Iron-Plating of Specimens for Microscopical Examination."

H. LIPSON and N. J. PETCH : " The Crystal Structure of Cementite, Fe_3C."

H. LIPSON and A. J. C. WILSON : " Some Properties of Alloy Equilibrium Diagrams Derived from the Principle of Lowest Free Energy."

P. LLOYD and E. A. C. CHAMBERLAIN : " Corrosion of Steels by Molten Nitrates."

L. REEVE : " The Corrosion of Mild and Copper-Bearing Steel Panels in Iron-Ore Wagons." (Paper No. 3/1940 of the Corrosion Committee (communicated by Dr. T. Swinden)).

T. SWINDEN and W. W. STEVENSON : " An Accelerated Spray Test for the Determination of the Relative Atmospheric Corrodibility of Ferrous Materials." (Paper No. 2/1940 of the Corrosion Committee (submitted by the Laboratory Research Sub-Committee)).

A. A. TIMMINS : " The Decomposition of Pearlite in Grey Cast Iron." (Andrew Carnegie Scholarship Memoir).

R. R. F. WALTON : " The Practical Side of Blast-Furnace Management, with Especial Reference to South African Conditions."

B. YANESKE : " The Manufacture of Steel by the Perrin Process."

Presentation of Papers.

The following papers were presented for discussion :

" The Manufacture of Steel by the Perrin Process," by B. YANESKE.
" The Practical Side of Blast-Furnace Management, with Especial Reference to South African Conditions," by R. R. F. WALTON.
" An Accelerated Spray Test for the Determination of the Relative Atmospheric Corrodibility of Ferrous Materials," by T. SWINDEN and W. W. STEVENSON. (Paper No. 2/1940 of the Corrosion Committee (submitted by the Laboratory Research Sub-Committee)).

The Meeting then adjourned for tea at 5 P.M.

EVENING SESSION.

After the tea interval, the Meeting was resumed at 6.15 P.M. ; the PRESIDENT (Mr. John Craig, C.B.E.) was in the Chair.

Presentation of Papers.

The following papers were presented for discussion :

" Non-Metallic Inclusions in Steel.   Quantitative Evaluation.—Part I.," by
   W. H. HATFIELD, F.R.S., and G. W. GILES.   (Paper No. 3/1940 of the
   Committee on the Heterogeneity of Steel Ingots (submitted by the
   Inclusions Sub-Committee)).
" The Influence of Some Special Elements upon the Strain-Ageing and Yield-
   Point Characteristics of Low-Carbon Steels," by C. A. EDWARDS, F.R.S.,
   D. L. PHILLIPS and H. N. JONES.

Vote of Thanks to the President.

Dr. W. H. HATFIELD, F.R.S. (Vice-President), proposed a vote
of thanks to the President (Mr. John Craig, C.B.E.) for having come
from Scotland to preside over the Meeting.   He did not know any
industrialist who had a greater load on his shoulders at the present
time, and he was sure that all the Members warmly appreciated the
President's action in giving up time to attend the Meeting.

The resolution was seconded by Dr. T. SWINDEN (Member of
Council); the PRESIDENT replied briefly and the proceedings then
terminated.

THE PRACTICAL SIDE OF BLAST-FURNACE MANAGEMENT, WITH ESPECIAL REFERENCE TO SOUTH AFRICAN CONDITIONS.[1]

By R. R. F. WALTON (PRETORIA, SOUTH AFRICA).

SUMMARY.

After a description of the two South African blast-furnace plants —the Pretoria plant of the South African Iron and Steel Industrial Corporation, Ltd., and the Newcastle plant of its associated company, African Metals Corporation, Ltd.—with details of the furnace lines, the raw materials used are discussed and the unusual nature of these is pointed out. The coke is high in ash and friable, and actual test figures are given, showing the effect on furnace operation of coke breeze of various sizes.

The operation and care of crushing, handling and charging appliances, stoves, Lodge-Cottrell and Theisen gas-cleaning plants and the gas distribution system are mentioned, and the following section deals with the handling of the furnaces. The method of blowing-in with the usual charge and the results attained are followed by notes on the necessity of regularity of the burden, charging and blast volume. Hanging and slipping and their prevention and cure are discussed, as are the care of the tap-hole, runners and ladles; a description of the mud-gun, dam and skimmer is included. The precautions taken during a plant stoppage are indicated, and details are given of unusual operating difficulties, including the use of dynamite in the bosh and well of a furnace. After dealing with the operation of the pig-casting machine, the paper ends with a section on the South African personnel and unusual weather conditions.

(1) *Brief Description of Plants.*

There are two blast-furnace plants in South Africa : the Pretoria plant of the South African Iron and Steel Industrial Corporation, Ltd., and the Newcastle plant of its associated company, African Metals Corporation, Ltd.

(a) *The Pretoria or Iscor Plant* consists of two primary and two secondary crushers, with duplicate conveying-belts, so that either primary crusher can work with either secondary crusher and deliver crushed ore and flux *via* either conveyor. The crushers are of the gyratory type, and can handle 500 tons of ore per hr. The crushed material is elevated to a transfer bin, from which it is drawn into electric transfer cars and dumped into the furnace-bins or the ore-trough, from which it is handled on to the stock-piles by means of a rope-trolley-type ore-bridge. The bins are of reinforced concrete.

The furnace charging is carried out by double skips, electrically

driven on an inclined hoist. Coke is drawn from coke-bins on either side of the hoist into automatic weigh-hoppers, which deliver into the skips. Ore and flux are handled in electric scale-cars of 10 tons capacity. The scale-car driver operates the whole of the charging system.

There are two furnaces, each of the following dimensions :

Height from hearth to top platform	86 ft. 6 in.
Hearth diameter .	16 ft. 1 in.
Bosh diameter	19 ft. 6 in.
Throat diameter .	14 ft. 0 in.
Bell diameter	10 ft. 0 in.
Height of bosh .	10 ft. 6 in.
Height of parallel section above bosh	7 ft. 0 in.
Depth of parallel section below platform	19 ft. 0 in.

Fig. 1 shows the lines of these furnaces.

The furnaces are equipped with McKee revolving tops. Hearth cooling consists of solid-drawn steel pipes cast in cast-iron staves, surrounded by a $1\frac{1}{2}$-in. mild-steel jacket. The bosh is of the banded type, cooled by copper plates, while the tuyere belt is a 1-in. mild-steel jacket pierced to take ten tuyeres and four rows of cooling-plates. There are seven rows of duplex copper plates above the lintel.

The metal is handled *via* cast-iron runners into 60-ton ladles, while two slag notches are provided. These consist of a cast-iron cooler with steel-pipe coil cast in, an intermediate copper slag-cooler and a 2-in. copper monkey. The slag is delivered into steam-tipped slag-ladles of 175 cu. ft. capacity.

An electric passenger lift is provided for access to the furnace tops.

There are five two-pass stoves, 21ft. 0 in. × 105 ft. 0 in., filled with Strack zoned checkers. No. 3 stove is so arranged as to be capable of being used on either furnace. This equipment allows of a blast temperature of 1600° F., using about 20% of the gas produced. The usual snort- and mixer-valves are incorporated in the blast mains.

The gas is drawn off by four off-takes, joining into two down-comers, which deliver in each case into a 30 ft. 0 in. plain dust-catcher, followed by a Vortex dust-catcher which removes about 60% of the remaining dust. The gas next passes into a precooler and then into the common cool-gas main, from which it is passed into either the Lodge-Cottrell gas-cleaner, which is a three-unit two-stage plant, or into two tower-washers followed by three Theisen disintegrators. One Lodge-Cottrell unit and one Theisen disintegrator are spares, the remaining units being sufficient to handle all the gas from two furnaces and clean it to 0·0070 grain of dust per cu. ft. The clean gas is delivered into a 2,000,000-cu. ft. gas-holder of the waterless type.

Normally molten metal is delivered direct to the melting-shop,

but, when necessary, the whole output can be handled in a two-strand pig-casting machine.

The water service is duplicated to each furnace and efficient strainers are provided.
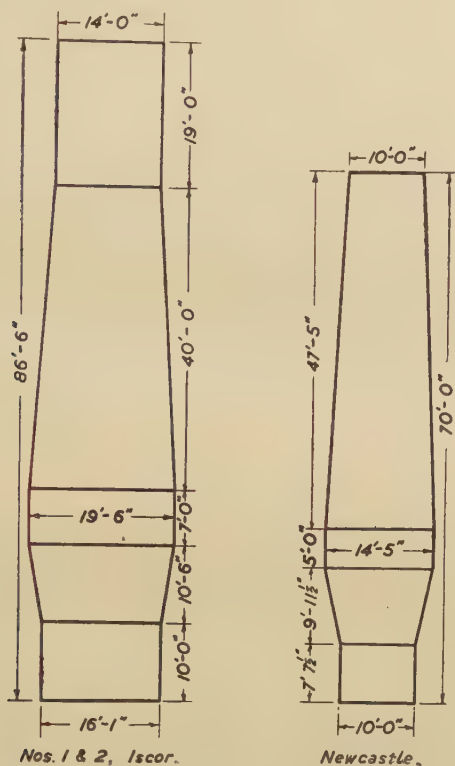

Fig. 1.—Lines of South African Furnaces.

(b) *The Newcastle Plant*, situated in Northern Natal, about 220 miles from Pretoria, consists of one blast-furnace having the following dimensions :

Height	.	.	.	.	70 ft. 0 in.
Hearth diameter	.	.	.	.	10 ft. 0 in.
Bosh diameter	.	.	.	.	14 ft. 5 in.
Throat diameter	.	.	.	.	10 ft. 0 in.
Bell diameter	.	.	.	.	6 ft. 0 in.

The hearth and bosh-jackets are of mild steel cooled by external sprays. In the mild-steel tuyere belt there are eight tuyeres and three rows of copper plates. There is one row of copper plates above the lintel. The furnace lines are shown in Fig. 1.

This furnace is charged by means of barrows carried by a double-cage vertical hoist. Most of the materials are delivered broken to size, but a small crushing plant is installed to deal chiefly with dolomite. The barrows are filled from concrete bins, the weight is adjusted and the barrows are hoisted to the top. Here they are dumped *via* a small bell on to the main bell and thence into the furnace.   Four stoves, 20 ft. 0 in. × 80 ft. 0 in., with 7-in. square checker openings, are provided.   One tower-washer and one Theisen disintegrator deal with the cleaning of the gas.   Either or both of these can be by-passed and semi-clean or crude gas used. The whole of the gas is used in the stoves or boilers. The latter are five in number, of the Babcock and Wilcox type. There are two Bellis and Morcom generators and one turbo-blower, with two reciprocating blowers as a stand-by. There is an ample supply of exceptionally soft water from the river 2000 ft. away. After circulation the water is returned to the river, except for the gas-cleaning system, where the water is cooled in a spray pond and re-circulated. This plant is used for the production of hematite and foundry pig and ferro-manganese and the whole output is sand-cast, the cast-house, as at Pretoria, being entirely covered. A 5-ton overhead crane and a pig-breaker are installed.

(2) *Raw Materials.*

Unlike general European practice, where moderate or poor ores are usually smelted with good coke, South African conditions call for the production of iron from exceedingly rich ores with poor coke. At Pretoria the usual ore mixture contains 64·0% of iron and 6·1% of silica, while the coke contains 16% of ash and only 82% of fixed carbon. About 3050 lb. of ore and 1530 lb. of coke are required to produce a short ton of metal. It will be seen, therefore, that the greater proportion of the slag-forming materials arises from the coke, and as this is only liberated when combustion of the coke takes place, there can be no comparison between the slag in the bosh zone and the final slag flushed from the furnace. It might be expected that the extremely limey slag at the top of the bosh would cause trouble, and that this is not so is partly due to the small weight of slag arising from the ore-bearing materials. Fortunately the two ores used contain 0·5% and 4·0% respectively of alumina, so that it is possible to balance the two to produce a slag containing about 16% of alumina, which gives a very free-flowing slag.

Iscor Works.

(a) *Ores.*—The two ores used at Iscor are Thabazimbi and Pretoria ore. The former is transported about 155 miles, while the latter is quarried on the property.

Average analyses are as follows :

					Thabazimbi.	Pretoria.
Iron	.	.	.	.	66·6%	50·0%
Silica	.	.	.	.	3·5%	20·0%
Alumina	.	.	.	.	0·5%	4·0%
Lime	.	.	.	.	0·1%	0·3%
Magnesia	.	.	.	.	0·1%	0·2%
Manganese	.	.	.	.	0·20%	0·2%
Phosphorus		.	.	.	0·025%	0·1%

Both ores are extremely dense, more especially the Thabazimbi ore, and are therefore crushed to $2\frac{1}{2}$ in. max. No grading of the ore is carried out at present, but plant is being installed to carry out furnace tests on graded burdens.

Because of the hard and abrasive nature of the ores, regular attention must be given to the crushers, which are re-set as wear takes place and remetalled or renewed as occasion requires.

(b) *Dolomite and Calcite.*—Both dolomite, obtained close to the works, and calcite are used as flux, the usual proportion being 65% of dolomite and 35% of calcite. Each flux has been used alone successfully, but the dolomite gives a more freely flowing slag.

Average analyses are as follows :

				Dolomite.	Limestone.
Silica	.	.	.	2·8%	1·0%
Alumina plus ferric oxide		.	.	2·1%	0·7%
Lime	.	.	.	29·3%	48·5%
Magnesia	.	.	.	19·6%	5·5%
Manganese oxide	.	.		1·0%	...

These fluxes are also crushed to $2\frac{1}{2}$ in. max. and used without screening.

(c) *Coke.*—The coke produced from Transvaal coals is high in ash —about 16%—due to difficulties in washing, brought about by the density of the coal and discard being very much the same. It has a low abrasive index, and about 15% is screened out as breeze below 1 in. and used elsewhere on the works. The coke is screened as it falls into the weigh-hoppers ready for charging, and all −1-in. material is rejected. Actual furnace tests carried out at Iscor to determine the value of this breeze gave the figures listed in Table I., after making allowance for runner and casting-machine scrap returned to the furnaces.

Table I. confirms the experience of other operators that coke below 1 in. has no furnace value.

As so great a proportion of the slag arises from the coke ash, it is necessary to keep a careful watch on the weight and ash content of the coke, because any difficulties at the washery or coke-ovens are at once reflected in the slag composition. The coke is dry-quenched, and can therefore be charged by weight when received direct from

TABLE I.—*Furnace Tests to Determine the Value of Coke Breeze.*

Test No.	1.	2.	3.
Furnace No.	2	2	2
Period. Days	21	21	21
Coke size. In.	$+\frac{1}{2}$	$+\frac{3}{4}$	$+1$
+ 1 in. coke. Lb. per ton of metal .	1675	1636	1635
$\frac{3}{4}$ to 1 in. coke. Lb. per ton of metal .	...	92	...
$\frac{1}{4}$ to 1 in. coke. Lb. per ton of metal .	89	...	...
Total coke. Lb. per ton of metal . .	1764	1728	1635
Silicon in metal, average. % . .	0·84	0·91	0·83
Sulphur in metal, average. % . .	0·031	0·027	0·028
Blast pressure, average. Lb. . .	15·44	13·45	12·50
Average hours per day when blast pressure was over 17 lb.	1·53	1·20	Nil

the ovens. If stock coke has to be charged, the moisture content must be known and allowed for.

Newcastle Works.

(a) *Ores.*—The iron ores used at Newcastle are Thabazimbi ore and ores from local surface deposits. The latter vary from 50 to 58% of metallic iron, with from 6 to 10% of silica, and are limonites. It is necessary to add sandstone to mixtures of these ores to produce a sufficient slag volume for effective desulphurisation, but this presents no difficulty. The distance from Thabazimbi to Newcastle is about 375 miles, while the local ore deposits are at an average distance of 30 miles.

(b) *Dolomite and Coke.*—Transvaal dolomite, similar to that used at Iscor, is the regular flux, while for phosphoric foundry irons, with up to 1·6% of phosphorus, phosphate rock is added to the burden.

The coke used is beehive and by-product coke produced in Northern Natal, and delivered to the works by rail. The average analysis is approximately :—

Fixed carbon	.	.	.	84·1%
Ash .	.	.	.	13·0%
Sulphur	.	.	.	0·9%
Moisture	.	.	.	2·0%

For the production of ferro-manganese the same coke and dolomite are used with manganese ore from the Postmasburg district of the Cape Province. The latter averages 50% of manganese, 7% of silica and 5–6% of iron, and is in dense lumps, which are broken to about 5-in. size for blast-furnace use. The usual 78–80% alloy is produced, the consumptions of raw materials being approximately :

Manganese ore	.	.	4,000 lb. per ton of alloy
Coke .	.	.	4,850 ,, ,, ,,
Dolomite.	.	.	2,100 ,, .. ,,

The output of foundry iron of all grades averages about 140 tons
per day and of ferro-manganese 63 tons per day.

(3) *Weighing Appliances.*

Coke weigh-hoppers and scale-cars must be kept in good order
and are checked regularly. In addition, scale-car drivers are required
to report immediately the zero adjustment of the indicators is found
not to be correct. A weekly check on the input and output of
metallic iron will at once reveal any inaccuracy in the weighing
apparatus.

A daily inspection of all wearing-plates in the weighing apparatus,
skips and small bell-hopper is carried out. Spare wearing-plates,
standardised so far as possible, are carried, so that replacements
can be made promptly.

(4) *Stoves.*

Care must be taken when using clean gas and pressure-burners
that stoves are not overheated. At Iscor a thermocouple is inserted
in the dome of each stove and a continuous record taken of the
temperature. Stove attendants are instructed not to allow the dome
temperature to exceed 2100° F. With stoves of sufficient capacity
this is ample to maintain a blast temperature of 1600° F. when
required.

All valves are examined regularly in order to see that they are
seating tightly and that the water supply to hot-blast and chimney
valves does not fail. Feed-pipes and valves, where water-cooling is
used, are flushed out regularly, especially in flood conditions, when
the water may carry high concentrations of solids in suspension.
The waste gases are tested about once every other week and the
combustion is adjusted to ensure that only the minimum volume
of gas is used, leaving as much as possible available for other parts
of the works. A volume indicator, showing the amount of gas being
burnt in the stoves, is fitted at Iscor; it is a useful check on the
efficiency of the combustion.

(5) *Gas-Cleaning Plants.*

(a) *The Lodge-Cottrell Plant* depends for its efficient operation on
the temperature and humidity of the gas it has to treat. A thermo-
stat and regulator govern the supply of water to the precoolers, and
it is essential that the bulb of the thermostat be kept clean. At
Iscor it was placed originally in the vertical main from the pre-
cooler to the cool-gas main. In this position it was found impossible
to keep it free from mud, so that it was removed to a position in the
cool-gas main, with very beneficial results. A recorder showing
the cool-gas temperature is placed in a convenient position, so
that the operators know that the regulator is functioning properly.

Both precooler and slat-tower sprays are of such a type that they can be withdrawn individually and cleaned during operation, and this should be done each shift. Fans and treaters should be taken off in rotation at regular intervals for cleaning and overhaul.

(b) *Theisen Plant.*—Feed-pipes for the water supply for both tower-washers and Theisen disintegrators are duplicated so far as possible, as constant recirculation of the water causes increased solids both in solution and suspension, and these build up in the water-pipes. The seals of the disintegrators are flushed out daily and the machines taken off for cleaning and inspection at regular intervals.

(c) *Gas Distribution.*—All mains have suitable drains delivering into seal-pots. These are flushed out weekly. Suitable connections on the mains are provided so that they can be swilled out with water into these seal-pots. It goes without saying that dust-catchers are emptied daily, and not allowed to accumulate dust.

(6) *Handling of the Furnace.*

(a) *Preparation of the Furnace.*—The following method of preparing and blowing in the furnace has been standardised in South Africa : When the brickwork is finished and the top gear in position, the tuyere coolers are rammed up from the inside with ground fireclay and brick, thoroughly packed in. A fire is then made on the hearth, the cooler apertures being bricked-in with a loose brick in each to allow of adjusting the draught. In the case of the Iscor furnaces, where there is always one in blast and the gas-holder maintains continuity of pressure and supply, blast-furnace gas is led into the fire through a 3-in. pipe after a couple of days. At Newcastle, where there is only one furnace, the fire is fed with coke and gently blown with compressed air. This drying is continued for 14 to 21 days, and meanwhile all the cooling plates are carefully pointed up on the outside with refractory cement.

After firing has finished and the brickwork has cooled down, about 3 in. of coke and tar mixture is rammed on the hearth in the shape of a saucer, to cover the horizontal joints where the brickwork is corbelled back to the same diameter as that of the wall of the well. A 6-in. pipe is placed in the tap-hole, about 3 ft. inside the well and extending about 4 ft. down the tapping-trough. This is rammed around with tap-hole clay from inside and outside. Four $1\frac{1}{4}$-in. holes are drilled in the pipe so that it can be turned to keep it free in the hole and to withdraw it later. Coke is then thrown in by hand to the level of the bottom of the tuyere arches, and all tuyeres but one are put into position. Three sacks of coke, one on each side and one on top, are put around each tuyere to protect it when filling begins from the top. Likewise old sleepers are placed against the bosh wall to protect the brickwork. The last tuyere is now put in

place, and a little kindling-wood and shavings are put in front of the nose of each tuyere. The blow-pipes and goose-necks are now fitted, and filling begins from the top. Table II. indicates a typical filling charge for one of the Iscor furnaces.

TABLE II.—*Typical Filling Charge for an Iscor Furnace.*

Set 1.	6 rounds, each of 4 skips of coke	at 2500 lb. per skip.
	No ore or dolomite.	
Set 2.	5 rounds, each of 4 skips of coke	at 2500 lb. per skip.
	1 skip of dolomite	2000 lb.
	1 skip of limestone	2000 ,,
	To be charged : 2 coke plus 1 dolomite on first bell.	
	2 coke plus 1 limestone on second bell.	
Set 3.	On first bell : 4 rounds, each of 4 skips of coke	at 2625 lb. per skip.
	On second bell : 1 skip { Thaba ore	1250 lb.
	{ dolomite	1100 ,,
	1 skip { Pretoria ore	1250 ,,
	{ limestone	1100 ,,
Set 4.	On first bell : 4 rounds, each of 4 skips of coke	at 2625 lb. per skip.
	On second bell : 1 skip { Thaba ore	2000 lb.
	{ dolomite	1150 ,,
	1 skip { Pretoria ore	2000 ,,
	{ limestone	1150 ,,
Set 5.	On first bell : 4 rounds, each of 4 skips of coke	at 2625 lb. per skip.
	On second bell : 1 skip { Thaba ore	2800 lb.
	{ dolomite	1400 ,,
	1 skip { Pretoria ore	2800 ,,
	{ limestone	1400 ,,
Set 6.	On first bell : 4 rounds, each of 4 skips of coke	at 2625 lb. per skip.
	On second bell : 1 skip { Thaba ore	4100 lb.
	{ dolomite	1650 ,,
	1 skip { Pretoria ore	4100 ,,
	{ limestone	1650 ,,
Set 7.	On first bell : 4 rounds, each of 4 skips of coke	at 2625 lb. per skip.
	On second bell : 1 skip { Thaba ore	5000 lb.
	{ dolomite	1900 ,,
	1 skip { Pretoria ore	5000 ,,
	{ limestone	1900 ,,
Set 8.	On first bell : 4 rounds, each of 4 skips of coke	at 2625 lb. per skip.
	On second bell : 1 skip { Thaba ore	5500 lb.
	{ dolomite	2000 ,,
	1 skip { Pretoria ore	5500 ,,
	{ limestone	2000 ,,

When the furnace is full to about 20 ft. from the top, the distribution is examined by getting into the furnace through the big bell, which should be propped open. Care must also be taken that the water-seal or other valve isolating this furnace from the common cool-gas main is not leaking. Filling proceeds to 5 ft. below the big bell, and the furnace is ready for lighting. The water supply to the various cooling members is adjusted, each tuyere and tap-hole is lighted with hot bars and hot blast is put on at about 10,000 cu. ft. per min. for half an hour, the gas escaping through the bleeders and

a little steam being turned into the main dust-catcher. After half
an hour the blast is taken off, the tuyere lids are opened and the
furnace is allowed to draught for 24 hr. Blast is then put on again,
and the gas is ignited at the pipe in the tap-hole and allowed to burn
there for about 2 hr. The pipe is then withdrawn and the tap-hole
plugged with the mud-gun. The gas is now of sufficient volume and
quality to be put into the system. The water-seal at the outlet of
the Vortex is emptied, and each vessel and main is purged in turn
until the gas is right through the system, when the valve to the
clean-gas main is opened and the operation is complete. The
history of this " blow-in " is represented in Table III.

TABLE III.—*History of the " Blow-In " of an Iscor Furnace.*

Nov. 24,	8.30 A.M.	Furnace lit up. Draughting until 8.45 A.M., Nov. 25.
Nov. 25,	8.45 A.M.	Blast put on; blast volume 15,000 cu. ft. per min. Nos. 2, 4, 6, 8 and 10 tuyeres closed.
	10.30 A.M.	Pipe withdrawn from tap-hole.
	11.30 A.M.	Blast increased to 20,000 cu. ft. and gas into the holder.
	3.30 P.M.	Opened Nos. 6 and 10 tuyeres and increased blast to 25,000 cu. ft. Furnace working freely and looking hot.
	8.15 P.M.	First slag. Hot and grey.
	8.30 P.M.	Blast increased to 28,000 cu. ft. 1000 lb. Thaba ore and 200 lb. dolomite added per round.
Nov. 26,	2.20 A.M.	No. 2 tuyere opened. Foreman's report says " Slag grey and hot. Impossible to be better."
	3.00 A.M.	Last flush of slag. 2⅜ ladles over notch. Furnace tapped. One ladle metal, 1¼ ladles roughing slag. Iron very grey.
	7.00 A.M.	1000 lb. Thaba and 200 lb. dolomite added per round. Nos. 4 and 8 tuyeres opened and blast increased to 30,000 cu. ft. All tuyeres now open.
	10.15 A.M.	Second cast. Iron hot and slag fluid. Burden increased by 1000 lb. Thaba ore and 300 lb. dolomite per round.
	2.40 P.M.	Third cast. Good metal. Furnace driving freely.
	6.50 P.M.	Fourth cast. Good metal. Furnace driving freely.

(b) *General Operation.*—The filling and distribution require
careful watching and checking. Charging must be regular and the
furnace kept as full as possible—to about 3 ft. below the big bell
when in the open position. In addition to the automatic stock-line
recorder, two other trial holes are provided, and it is customary to
check up on these regularly to ensure that the distribution is even
and the stock is level in the furnace. The coke charge is as large
as possible, consistent with the capacity of the bell and hopper,
as it is found that most furnaces work better the bigger the
coke charge. At Iscor the coke charge is 10,500 lb. charged in four
skips on the first bell, followed by two skips of ore and one of flux

on the second bell. At Newcastle the coke charge weighs 4800 lb. charged on the first bell in six barrows, followed by six barrows of ore and three of flux on the second bell.

It is the author's practice, so far as possible, to keep both the burden and blast volume constant for any one grade of iron and to make all necessary adjustments by alteration of the blast temperature. For any furnace there is an optimum blast volume, which can only be determined by experiment. When this has been fixed the burden is adjusted so that normally there is ample reserve of blast temperature in hand. The foremen have only to adjust this to keep the furnace on a constant grade of metal. When making basic metal for the open-hearth plant the furnaces often run for months on end without alter-ation of blast volume or burden, keeping the product constantly between $0·5\%$ and $0·9\%$ of silicon. The practice is admittedly more difficult where the use of several different ores necessitates changes of burden, but the practice often met with of changing the blast volume to meet variations in slag composition and furnace conditions is obviously unsatisfactory.

(c) *Hanging and Slipping* are very rare occurrences when working to the method described. Hanging usually begins because of the furnace running too hot or too cold. The appearances of the crude gas, the tuyeres and the slag at once indicate in which direction the furnace is swinging, and suitable adjustment of the blast temperature, with gentle checking of the furnace, will overcome it in the early stages. If possible, the furnace is allowed to slip on its own by adjustment of the blast temperature, but if checking is necessary, it is accomplished by signalling the blowers to ease down, with the snort-valve shut. This ensures a cushion of blast to prevent the burden from slipping heavily into the converging lines of the bosh and jamming tightly, so that the gas cannot penetrate the coke and slag in the bosh. This condition is recognised by the difficulty of forcing a bar through the tuyeres. A further danger in the sudden slipping of the furnace is the possible loss of tuyeres due to slag or metal being forced up to them.

Incorrect tuyere size for the particular furnace and volume of air blown will also cause irregular working, due to pillars either between the adjoining tuyeres or in the centre of the furnace. Tuyeres of different length or diameter will correct this, but, con-sistent with regular working, tuyeres should be as short as possible. To illustrate this, Iscor No. 1 furnace worked throughout 1938 and 1939 with 12 in. $\times$ 5-in. tuyeres of standard design, and the average life per tuyere was 429 days. During the same two years No. 2 furnace, working on the same burden and grade of metal, with 15 in. $\times$ 5$\frac{1}{2}$-in. tuyeres, had an average tuyere life of 203 days. Both furnaces worked freely and well, and there were no signs of pillars or scaffolds. Both sizes of tuyeres were of the same general design and supplied by the same maker. The water strainers at the furnaces are changed over and cleaned regularly, and the individual cocks for

the cooling members are of the three-way type, so that they can be flushed regularly.

(d) *Care of Tap-Hole, Ladles, &c.*—At Iscor Brosius electric clay guns are used and the tap-hole is stopped against pressure. The local clays are highly aluminous with consequent heavy shrinkage, so that a proportion of the shale is calcined in the dolomite kilns before use. The tap-hole is kept well back inside the collar and is drilled with a rotary air drill with a 2-in. bit.   The tapping trough is made up to a constant level each time by the use of a gauge and the hole is drilled regularly at the same angle.   The skimmer is made up of 13½-in. firebricks held in a channel-iron frame, while the dam consists of four 9-in. firebricks, two on edge 3 in. apart in the runner, and two on the flat laid over them, giving a hole 3 in. square. This aperture is filled with hot sand and the whole of the dam is rammed over with loam, which is also used in the runners, and dried with blast-furnace gas. The levels of the dam and skimmer are arranged so that the gun nozzle does not travel through the metal when entering the tap-hole. While the gun is in the hole the loam is cut away to expose the aperture through the dam and a pricker rod pushed through to release the metal behind the dam.

The hot-metal ladles are of the enclosed type and hold 60 short tons.   They have a course of insulating brick next to the shell and two courses of firebrick.   It is customary to get about 300 to 350 casts, after which the inner course is renewed. With this type of ladle it is necessary to clean up the throat each time they come back from the melting-shop or casting-machine, especially if there has been much delay in pouring. Occasionally it is necessary to burn accumulations off the lip with oxygen.

Slag ladles are simply grouted with clay-wash. Originally cast-iron pots were used, but were later replaced by steel pots, which gave about four times the life.   Instead of being supported in the collar of the carriage by cast-on lugs, they are now held in a basket of steel flats which gives support all round the ladle and reduces warpage.

(e) *Precautions when Stopped.*—With the Baer explosion valves fitted to the bleeders it is impossible to get rid of the gas in the furnace sufficiently quickly when stopped to change tuyeres, &c. It is then necessary to pull the gas back through one of the stoves to the chimney. There is an element of danger in this, as there is the possibility of blast leakage from the chimney valves or blow-down valve of the stove on blast on the other furnace, or of infiltration of air into the chimney flue, due to the suction of the chimney, either of which may cause an explosion.   The water-seal is therefore filled to prevent gas from coming back from the common cool-gas main and the sight-holes of the tuyeres are opened, so that the gas pulled back to the stove burns in the bustle pipe and hot-blast main.   The blower is also kept going and blowing through the snort-valve, and the mixer valve is closed, to prevent gas from getting back into the cold-blast main.

(f) *Water Leakage*.—With the multiplicity of cooling-plates, &c., in a blast-furnace, the difficulty of detecting leakage from any one member often arises, especially as the water is sometimes so unkind as to appear far away from the place affected. The following ex- perience will illustrate this : About midnight, on December 13th, 1936, water began to come back around Nos. 2 and 3 tuyeres on No. 1 furnace. No. 1 tuyere is over the tap-hole and the ten tuyeres are numbered clockwise. These tuyeres were taken out and found to be intact, as were the corresponding coolers. Meanwhile, with the blast off, water began to appear at tuyeres and plates all round the furnace, and a trickle of water flowed down the tapping trough from the side of the tap-hole. A systematic search was thus necessary, and this was carried out by putting a piece of hose-pipe on each outlet in turn. This was bent into a U-tube, the feed-cock turned off quickly and the water in the U-tube watched to see if its level sank. By this method the cast-iron slag-coil was found to be leaking, though no water appeared at the slag-notch. This coil was changed, and the water at the tap-hole began to grow less, so that the furnace was prepared for restarting. The tap-hole was naturally cold and hard, and while burning it out with oxygen water began to flow freely through the tap-hole, to the extent of a stream about $1\frac{1}{2}$ in. deep in the trough. The furnace was again stopped and the systematic examination continued on the plates, &c., not previously tested. Eventually on trying the U-pipe on the outlet from the hearth- jacket stave under No. 6 tuyere, this member was found to be leaking badly. In a few minutes after turning off the water the stream at the tap-hole disappeared. Fortunately a good coke blank, followed by a lighter burden, had been charged after the first stop- page, and the furnace was quickly normal again. The peculiar feature of this trouble was that the source of the water running from the tap-hole was 180° away, and yet found its way around the furnace.

(g) *Use of Dynamite*.—Another personal experience of an unusual nature may be of interest. On December 1st, 1938, the author was called to the Newcastle furnace, which at the time was making ferro-manganese. The furnace was badly " limed up," dead cold, and making no gas. There had been a stoppage on November 28th to clean out the gas mains.   On re-starting, the steam was low and only slack blast could be blown. There was not enough gas for the stoves, and the furnace got colder as the blast temperature fell, and on the author's arrival the position was desperate. It was arranged to charge a coke blank and put on an iron burden, but the furnace was not taking the blast, and little charging could be done. The usual procedure using sand, oxygen and oil was tried, and the three front tuyeres were kept open for some time and several lots of half-fused material got out of the tap-hole and slag-notch. In spite of all efforts, these tuyeres were finally lost on the night of December 4th. They were again burnt out with oxygen, but could not be kept open,

and it was decided to blast out the solid material. All tuyeres and coolers were taken out, and blasting started in the slag-notch and tap-hole, 36 sticks of gelignite in the slag-notch and 24 in the tap-hole. This was continued all night of the 5th, the lumps being removed through the tap-hole after each blast. During December 6th all tuyeres were dynamited out, and it was then obvious that it was solid up in the bosh. On December 7th a 1 ft. 6-in. hole was cut in the shell about 2 ft. 6 in. above the lintel, and on drilling through the brickwork good hot coke was found. A hole was then cut about half-way up the bosh, and heavy charges—96 sticks in one case— were fired. Eventually the bosh was blasted clear and the dead material raked out of the tuyeres. Good hot coke then came down and filled the bosh. Plates were welded over the holes cut in the shaft and bosh, and the furnace was prepared for restarting. It got away at 8 P.M. on December 8th, and gas was in the stoves at 9.30 P.M., and the trouble was over.

(7) *Pig-Casting Machine.*

This item of the plant gives little trouble, provided that ample water is available and all sprays are kept in good repair. Those on the conveyor rails at the pouring spouts and on the shot plates are kept going to prevent metal from building up, and a labourer is stationed at the latter point to rake away the shot as it is formed. Careful pouring and attention to the lime-sprays are essential to keep scrap down to a minimum. It has been found very helpful to place 30-lb. rails, spaced so that the lime-sprays can still reach the moulds, over the lime-vat and below the moulds as they return in the inverted position. This prevents pigs stuck in the moulds from falling on to the lime-sprays or tank. Especially when casting basic metal, it is necessary to have a man with a chisel bar near the top of the strand to ease up the pigs before they reach the discharge chute.

(8) *Personnel.*

It has been necessary in South Africa, as in other new countries, to train local men, including natives, for blast-furnace work. Originally three foremen were brought out from England, and they have been responsible, under the manager, for the training of local labour with which both plants are staffed. The proportion of natives to Europeans is about 3 to 1, and on the furnaces themselves the only European is the keeper. The local labour has adapted itself remarkably well to blast-furnace conditions, especially as the climate is rather hot.

Protective clothing in the way of goggles, gaiters of canvas impregnated with alum, and asbestos coats and gauntlets are provided for natives about the furnace and pig-casting machine, as their usual clothes are often of the sketchiest kind.

All Europeans are trained in the use of gas-masks and are subject to half-yearly examination and training. First-aid training is also provided. A large, airy change-house is available, and is more or less a necessity in this climate. The usual three eight-hour shifts are worked, but on the average only 48 hr. per week. Relief men are used and their duties arranged so that each man has a long week-end off every third week. All workmen have three weeks' paid leave per year and a holiday bonus, based on actual earnings.

(9) *General.*

Both in the Transvaal and in Natal the bulk of rainfall occurs in the summer months—October to March—and mostly in the way of heavy thunderstorms. On occasion 4 or 5 in. of rain may fall in as many hours. It is necessary therefore to provide ample storm-water drains and to see that these are kept open. All low points, such as stock-house, skip-pits and weighbridge sumps, which cannot be drained into these sewers, must have pumps or other apparatus installed. During these periods of heavy precipitation the furnace burdens must be adjusted to allow for absorbed moisture, which is often very heavy.

Lubrication of plant is, of course, an important item, and has to be carefully checked, especially at those points which are not very accessible, such as the furnace tops, rope-sheaves, bell-cranks, &c.

The author is indebted to the Management of the South African Iron and Steel Industrial Corporation, Ltd., for permission to publish this paper and to use their information and records.

DISCUSSION.

In the absence of the AUTHOR, this paper was presented by Mr. J. E. HOLGATE (London).

Mr. J. E. HOLGATE (London) said that, in view of his former association with South Africa, he was very pleased, in the author's absence, to present his paper for him.   Although it was not a very scientific paper, it contained a great deal of practical knowledge and information on modern plant, and it gave much food for thought.

Mr. Holgate continued that, in collaboration with the late Mr. A. K. Reese, he had been responsible for starting up the first commercial blast-furnace in Africa, in 1926, and at that time they gained a great deal of valuable information about raw materials and coke, the various methods of manufacture of coke and the characteristics of the smelting operations, at a small plant in Newcastle, Natal.   That was to a large extent a pioneer venture, but he thought it had laid the foundation in some ways for the more advanced plant which had been erected at Pretoria.

In 1928 he had collaborated with Mr. Walton, who was his assistant at that time, in writing a joint paper which was presented to the Institute, describing the manufacture of pig-iron in Natal.[1] They experienced many difficulties with imperfect plant, but as a result of their endeavours at that time they learned a great deal about the manufacture of pig iron under those diffi-culties, and the plant described in the present paper was to some extent a logical result of the pioneer efforts of fourteen years ago.

He was quite sure that the information contained in the paper would be of interest to operators and engineers in the blast-furnace world, as much of it related to modern methods and plant, and he would like to congratulate the author on his contribution to the existing fund of practical experience.

He thought that the plant at Pretoria followed fairly well the general principles of blast-furnace design, certain adaptations having been made to meet the local conditions.   There were similar plants in Great Britain.   The Corby plant, the Ford plant, Colville's in Scotland and the United Steel Companies had all come to the fore in recent years, and with their modern design were producing excellent results.   The paper gave a full description of all the processes which were indispensable to-day in high-capacity units, and it would be noticed that a gas-holder of 2,000,000 cu. ft. had been provided, which was also, of course, an important feature of the gas control system.

There were two ores available, the cheaper of which was the local Pretoria ore, a very refractory quartzite ore, with 50% of

[1] *Journal of the Iron and Steel Institute,* 1928, No. I., p. 209.

iron and 20% of silica. That was mixed in an approximately 50/50 blend with a much richer ore which came from a part of the Transvaal about 150 miles away and which contained 66–67% of iron and only 3·5% of silica. There was a wonderful deposit of that ore existing there to-day, the tonnages being almost unlimited.

It would be observed in the paper that the first consideration had been to crush the ore down to about 2½ in. maximum cube. It would be recollected that at the last Meeting of The Iron and Steel Institute Colclough,[1] in discussing Haven's paper, had laid great stress on the necessity for sizing the materials and crushing the ores if one wished to get the best blast-furnace practice, and that had been very fully borne out in Pretoria.

With regard to the crushing of the ores, although he noticed that the author referred to the possibilities of grading, he was not quite clear how far it would really be necessary to develop that idea. In view of the very hard ores used, he did not think there was likely to be a necessity for very much in the way of fines or smaller material.

The author dealt very briefly with the subject of coke. The Transvaal coal at one time was considered to be of very poor coking quality. In the early days experiments were made with mixtures of this and the very excellent coking Natal coals, but the experimenters did not get very far then. Since that time, however, a great deal of investigation had been carried out with selected seams of coal, and with the modern battery now installed at Pretoria he believed that a reasonably good coke had been produced, although it had an ash content of 16% and a low abrasive index. It was rather remarkable that the coke consumptions of the furnaces at Pretoria had been indicated as running in the order of 15–16 cwt. per ton of pig iron. That was quite a notable figure, in view of the fact that, as far as he knew, no outside scrap was melted in the furnace and the coke was definitely of a softer character than the majority of grades in Great Britain. He agreed with the author that the coke smaller than 1 in. was of practically no value in the blast-furnace, and he had carried out some inter-esting experiments to show the disadvantages of charging small coke.

The author referred on p. 23 P to the question of constant burden and blast volume and indicated, quite rightly, how desirable such conditions were in blast-furnace operation for a given grade of metal. The author was very fortunate in being able to keep the burden and blast volume constant for several months on end whilst maintaining a regular grade of basic iron. That showed the correctness of the furnace lines and it demonstrated the very uniform mechanical and chemical condition of the ores and the coke. Incidentally, the coke was all dry-quenched, so that the author was free from one trouble with regard to the coke, *i.e.*,

[1] *Journal of the Iron and Steel Institute,* 1940, No. I., p. 448 P.

varying moisture content, of which operators in Britain had much experience. He thought it was the dream of blast-furnace managers in this country to visualise the possibility of full outputs and uniform grades by a mere occasional flick of the blast temperature control; their life would be very easy if they could operate their furnaces in that way. He saw a great deal of blast-furnace practice up and down the country, and his sympathies went out to the blast-furnace managers to-day, especially at the smaller plants, where they had to face the constant changing of ore mixtures, fluctuations in analysis, and variations in the coke drawn from different areas. He thought most of the blast-furnace managers in Britain to-day were to be congratulated on the way in which they were able to keep their furnaces on an even keel under the present very adverse circumstances.

The author mentioned the two types of gas-cleaning plant that were now installed at Pretoria. He (Mr. Holgate) had not been to Pretoria for some years and he was not aware of the reasons for installing the complete Theisen wet-washing plant plus the towers, after the success that had been experienced with the original electrostatic plant which had been installed at the beginning on the first furnace that was operated. There had probably been good reasons—he did not know whether they were technical or commercial—for putting down a Theisen wet-washing plant instead of enlarging the electrostatic plant; it might be that there was some association between the two, and he would be interested to know how the two gas-cleaning plants operated to-day as a composite arrangement.

The manufacture of ferro-manganese at Newcastle raised another matter. He had had a little to do with the earlier considerations of that subject and he felt that, with a plant that was designed for that special practice, given clean gas and suitable stoves and methods of handling materials, and with the wonderful manganese deposits in the Postmasburg district and the cheap coal that was still mined in Natal and the Transvaal to-day, there were great possibilities for the manufacture of ferro-alloys in South Africa.

He was very pleased that Mr. Walton had presented the paper to the Institute, and he felt that the work done at Pretoria, particularly on the blast-furnace plant, must be the keystone of the whole future development of the iron and steel industry of South Africa, which, he thought, promised very well indeed, in view of the wonderful natural resources in the way of raw materials and the excellence of the labour conditions.

Dr. D. F. Marshall (Rotherham) said that Mr. Holgate, in presenting the paper, had referred to the very low coke consumptions of the Pretoria furnaces. From the description of the plant it would appear that the screening of the coke over a relatively

large mesh and the grading of other raw materials played a major part in producing this result.

Although all blast-furnace operators were fully aware of the deleterious effect of coke breeze on furnace performance, very little effort had been made to establish the effects quantitatively. For this reason it would be interesting to have more detail in Table I. As it stood, the Table clearly indicated a reduction in coke consumption and a more freely driving furnace resulting from the elimination of coke fines. It would be extremely interesting to know if the observed reductions in blast pressure were accompanied by increases in temperature of the blast, since similar changes in these two variables were noted by the speaker during blast-furnace trials reported to the Iron and Steel Institute in 1933.[1]

Mr. J. MITCHELL (Kettering) said that there was one omission from the author's excellent presentment of South African practice, namely, the output of the Pretoria furnace. He would like to know what that figure was, because the lines of the furnace, using a very dense ore difficult to reduce, did not suggest a sufficiently good time factor for large outputs.

Mr. J. S. GERBER (Low Moor, near Bradford) said he would like a typical analysis of the pig iron produced in the Pretoria plant to be given.

Mr. R. C. TUCKER (Sheffield), referring to the removal of breeze, said that the situation in Pretoria with regard to the disposal of this material might be more difficult than it was in a wet and colder country like England, where there was a ready market for the larger sizes of the breeze. He would like to know whether there was a market for the breeze in South Africa.

Mr. FRED CLEMENTS (Vice-President, Rotherham) said he had read the paper with considerable interest and that interest had been enhanced by the personal reminiscences which Mr. Holgate had given in introducing the paper. He confessed to a little disappointment when he first read the paper, because in these days, when so much investigatory work had been carried out on blast-furnace practice, one was accustomed to compare one practice with another, and, in order to do that, it was necessary to be in possession of a fair amount of technical detail. This was especially valuable when an opportunity such as the present arose for hearing about experience in a distant part of the world, but unfortunately the required information did not appear in the paper. He did not wish to appear critical, because the paper was a good one in many ways and was what it set out to be, *i.e.*, a practical paper, but if the author could give in his reply some further technical details

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[1] *Journal of the Iron and Steel Institute*, 1933, No. I., p. 87.

of his operating practice the value of the paper, he thought, would be greatly enhanced.

It was always interesting to have a record of developments which had taken place in various parts of the Empire. He believed he was right in saying that what had been done at Pretoria had been under review for a long time before it became a practical proposition. It seemed to him that Nature had a way of providing blast-furnace men with plenty of work to do in order to overcome the natural disabilities which were so often present. For instance, in India there was excellent ore but poor coke ; in Australia there was ore of the highest grade but it was nearly 2000 miles away from the coal, and so on. He could not help thinking that those engaged in the iron and steel industry in Britain had a great deal to be thankful for ; in fact, he did not think they counted their blessings as much as they ought to do, for it was difficult to imagine circumstances so favourable to the iron and steel industry as those that prevailed here, provided that they were made use of to the fullest extent. He felt, as he looked back over the last twenty years, that perhaps the industry had rather failed to do that, and he hoped when the time of post-war development came it would not so fail again. In some directions the failure had already been made good. Certain plants had been mentioned by Mr. Holgate which were typical of what a blast-furnace plant should be, and in the latest example, namely, the new blast-furnace plant of the Appleby-Frodingham Company, he thought the results would stand comparison with those of any other plant in the world.

Some of the experiences related in the paper were interesting and not entirely uncommon. For instance, the author called attention to the need for seeing that the thermocouple of the pre-cooler of the gas-cleaning plant was kept quite clean. That sounded a very trivial thing, but he remembered the following incident. The manager of a well-known blast-furnace plant in Britain was very proud of the regularity of his furnace top temperatures ; they were in fact so regular that one could not believe them. It was difficult to suggest such a thing, but he did venture to recommend the manager to have the thermocouple taken out and cleaned. When that was done, the results as shown on the subsequent temperature diagrams were similar to those from other blast-furnaces. Such things, although they might seem trivial, could in fact lead one very widely astray.

Mr. J. E. HOLGATE, following the discussion, said he thought it would be more appropriate for the author to reply in detail to the points that had been raised, but he would like to refer to some of the remarks made in the discussion.

With regard to the sizing of the coke and the possibility of increasing the blast temperature, he thought that it would no doubt

be possible to use considerably higher temperatures as a result of the screening of the coke than could normally be used without screening. The author would be able to give some information on that point.

As to the output, it was true that the figure was not given in the paper, but he believed that it was roughly about 350–400 tons per day. The original design, he thought, had been for a 300-ton furnace, but the plant had gone very much further than the original schedule of tonnages and he knew, from what the author had told him in correspondence, that it had reached some rather high records from time to time.

He had no accurate figures with regard to the pig-iron analysis. He thought the phosphorus would not exceed 0.2% or 0.25%. The silicon was 0.5–0.9%, and the sulphur was in the normal range.

With regard to breeze, it was stated in the paper that the breeze screened out of the coke was used on the works for other purposes, so no doubt some way had been found for disposing of it internally.

He was sure all the Members present had appreciated Mr. Clements' contribution to the discussion, and he hoped that the author would be prepared to give a little more detail with regard to his practice at some future date. The paper covered a great deal of ground, and the author had refrained from giving very much detail of the actual operations.

CORRESPONDENCE.

Mr. W. R. Brown (Stockton-on-Tees) wrote that Mr. Walton's paper was a contribution that would be read with great interest by many, especially by those concerned with the practical side of blast-furnace work. There was nothing in his paper which might be omitted, but there was much that whetted the appetite for more. The making of a long ton of iron with 15·3 cwt. of coke was a sufficiently outstanding achievement to arouse interest in all relevant data, e.g., blast temperature, analysis of slag and gas, &c. The author must also have some interesting figures comparing the operating results and costs of the two types of gas-cleaning plant installed at the Pretoria Works; perhaps in a future paper he would discuss these matters more fully.

On p. 16 Mr. Walton referred to the coke rate as 1530 lb. per short ton of metal and on p. 18 a somewhat higher rate per ton was given. The writer assumed that the latter referred to long tons.

The author gave figures denoting exceptionally long lives of tuyeres. To what cause did he attribute this phenomenon?

On p. 24 the necessity for pulling the gas back through a stove when the furnace was " on stop " to change tuyeres was expressed in a manner that suggested that the Baer valves were too small. Was not the resistance imposed by the burden in the shaft of the furnace the main factor that made this practice necessary ?

The author hardly did credit to himself and his colleagues in his matter-of-fact account of operations, for his reticence had not permitted him to picture to his readers the self-reliance, initiative and energy that must have been displayed in so successfully start- ing and running a new plant in a country far removed from other ironmaking centres.

The author's reply had not been received at the time of going to press, but it is hoped to publish it in the next volume of the *Journal.*

THE MANUFACTURE OF STEEL BY THE PERRIN PROCESS.[1]

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SUMMARY.

A new steelmaking process that can be operated on a large commercial scale is described, in which molten pig iron containing about 0·30% of phosphorus is blown in an acid-lined Bessemer converter, and the resultant blown metal is rapidly dephosphorised by pouring it from a sufficient height into a basic oxidising slag contained in the casting ladle. Alloys are then added in a red-hot condition to the dephosphorised blown metal and the finished steel is cast into ingots. By this method low-carbon-steel ingots can be manufactured direct from the acid Bessemer converter when using a pig iron that is too high in phosphorus for the normal acid Bessemer process.

The slag employed for the dephosphorisation of the Bessemer blown metal may either be a synthetic slag, or a basic open-hearth furnace slag sufficiently low in acids and high in iron oxide, such as may be obtained in the making of a low-carbon rimming steel heat. Examples are given, however, showing that the dephosphorisation is not so intensive with a basic open-hearth slag as with the synthetic slag, owing to the much lower acid content of the latter. It is also shown that the intensity of the dephosphorisation can be regulated to a certain extent by the percentage of dephosphorising slag employed.

For the production of acid open-hearth steel from the same phosphorus-bearing pig iron, a duplex process is employed in which the dephosphorised partly-blown metal containing a sufficient percentage of carbon is charged into an acid open-hearth furnace and the heat finished under an acid slag to the required chemical composition.

INTRODUCTION.

IN October 1935, the author, accompanied by Mr. J. J. Ghandy, General Manager of the Tata Iron and Steel Company, Ltd., Jamshedpur, India, visited the electric steel works of the Société d'Electro-Chimie, d'Electro-Métallurgie et des Aciéries Electriques d'Ugine, France, for the purpose of investigating the possibility of operating at the Tata Works the steelmaking process invented by Mr. R. M. V. Perrin, Director of the aforesaid French Company.

Mr. Perrin, who met Mr. Ghandy and the author at Ugine, explained that his process, which was patented in all steelmaking countries, consisted of the treatment of molten steel by pouring it

from a considerable height, say, about 20 ft., into a previously prepared synthetic slag contained in the casting ladle, or by other means churning the steel and slag together before casting the steel into ingots. Mr. Perrin stated that his process could be used either for deoxidising or dephosphorising molten steel, by varying the composition of the synthetic slag.

For *deoxidising* purposes, the slag had to be highly silicious, the silica content being not less than 55%, and the iron oxide ($FeO + Fe_2O_3$) content essentially as low as possible, preferably not above 1%. Mr. Perrin claimed that during the churning operation oxygen in the form of ferrous oxide was absorbed by the slag from the steel, *i.e.*, the steel was deoxidised not in the usual way, by the addition of deoxidisers which gave rise to solid inclusions, but by the actual removal of the ferrous oxide in accordance with the following equation :

$$2FeO + SiO_2 = Fe_2SiO_4.$$
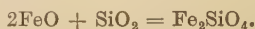
At the same time silicon also entered the steel by reduction of silica from the slag. Therefore, the result was that the deoxidised steel was free from non-metallic inclusions, since no inclusions could be formed in the process, this assertion being supported by practical results. Mr. Perrin stated that about 3% of synthetic slag was sufficient to obtain a satisfactory degree of deoxidation.

For *dephosphorising* purposes, a highly basic oxidising slag was necessary, the lime content being preferred above 55%, and the iron oxide ($FeO + Fe_2O_3$) content not less than 25%. Mr. Perrin claimed that when molten steel was churned with this molten synthetic slag, the phosphorus in the steel was oxidised to phosphoric acid, which combined with the lime in the slag to form calcium phosphate according to the following equation :

$$3CaO + P_2O_5 = Ca_3(PO_4)_2,$$
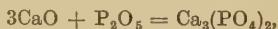
the calcium phosphate being retained in the slag. Thus there was a considerable increase in the P_2O_5 content of the slag, with the resultant possibility of utilising the finished slag as an artificial fertiliser, if the percentage of phosphorus to be removed from the steel were sufficient. Mr. Perrin stated that after the churning operation there was a remarkable decrease in the total iron oxide content of the slag, which was sometimes diminished from 35% to as low as 6 or 7%, iron thus being reduced from the slag to the steel and so increasing the yield. Mr. Perrin also claimed that he had found the dephosphorisation to be very intensive, even when starting from a low initial phosphorus content, and that the exothermic dephosphorising reaction which occurred in the ladle was completed in less than one minute for 15 tons of steel. With reference to the quantity of synthetic slag required, Mr. Perrin stated that it might vary from 5 to 15% of the weight of steel, depending on the percentage of phosphorus to be removed from

the steel, and also on the pouring height or the intensity of the churning of the steel and slag together.

As Mr. Ghandy and the author had in view the economic application of Mr. Perrin's process for the manufacture of low-carbon steels direct from Tata blast-furnace iron containing 0·28–0·40% of phosphorus, after blowing it in an acid Bessemer converter, thus eliminating the basic open-hearth furnace for finishing the blown metal, they were more interested in the *dephosphorising* process. It was therefore arranged with Mr. Perrin that two experiments in dephosphorisation would be carried out at the Ugine steelworks in their presence.

Preliminary Experiments on the Dephosphorisation of Steel with a Synthetic Slag at the Ugine Steelworks, France.

(A) *Dephosphorising Experiment with Very Low Percentage of Manganese in the Steel.*

The object of this experiment was to dephosphorise in the ladle to below 0·05% of phosphorus, steel which was low in carbon, manganese and silicon, but contained about 0·30% of phosphorus. This composition would therefore be similar to that of the Bessemer soft blows at the duplex plant of the Tata Iron and Steel Works at Jamshedpur, India, where the duplex process is operated by blowing iron in a 25-ton acid Bessemer converter and then trans-ferring the blown metal to a 250-ton basic open-hearth tilting furnace to dephosphorise and finish the steel to the required chemical specification.[1] The experiment would therefore demonstrate the possibility of dephosphorising Tata Bessemer blown metal by the Perrin process.

Mr. Perrin stated that in order to remove about 0·275% of phosphorus from the steel he considered about 10–12% of synthetic slag would be necessary in the experiment, but this amount could be reduced to about 7% by well shaking the steel and slag together, or by pouring the steel into the slag from a height of not less than 20 ft. Mr. Perrin was of the opinion that by using only 7% of slag it would be possible to obtain about 10% of P_2O_5 in the slag after the mixing operation.

Preparation of the Dephosphorising Slag.

A synthetic basic slag was prepared in a 5-ton Girod-Héroult basic-lined electric-arc furnace. The slag consisted of a mixture of lime, iron ore and a little fluorspar. In order to start making the slag, 2500 kg. ($2\frac{1}{2}$ tons) of Armco iron were charged in the empty furnace in order to produce the necessary electric circuit. On the

[1] The duplex process as operated in India at the works of The Tata Iron and Steel Company has been described by the author in a paper published in the *Journal of the Iron and Steel Institute*, 1927, No. I., pp. 181–209.

top of this iron, the following ingredients for making the slag were
charged :

		Kg.	(Cwt.).
Lime (CaO 85%)	. . .	1400	(28)
Iron ore (FeO 65%) .	. .	800	(16)
Fluorspar (CaF$_2$ 85%)	. .	175	(3½)

Mr. Perrin was aiming at the following composition of the slag,
with which he previously had obtained very good results :

CaO. %.	FeO + Fe$_2$O$_3$. %.	SiO$_2$, Al$_2$O$_3$, MgO, &c. %.
60	30	10

Preparation of the Steel for Dephosphorising.

In an adjacent 15-ton Girod-Héroult basic-lined electric-arc
furnace, a charge consisting of 12,000 kg. (12 tons) of plain carbon-
steel bloom butts and broken rails was melted with 1000 kg. (1 ton)
of calcined lime. After the bath was clear melted, the slag was
poured off. The following is a record of the heat from this stage :

Heat No. 92,440. 8th October, 1935.

	P.M.
First slag poured off	. 3.25–3.28
Lime added to clean bath (200 kg. (4 cwt.)) . .	. 3.30
All slag raked off	. 3.40–3.48
Ferro-phosphorus added, P 24%, Si 5% (150 kg. (3 cwt.)) .	3.50
Sample of steel	. 3.53
Furnace tapped (steel poured into slag) . . .	. 3.54
Slag Furnace.	
Sample of slag	. 3.43
Slag tapped into casting ladle (2000 kg. (2 tons)) .	. 3.51

The pouring height from the furnace launder to the bottom of
the casting ladle was approximately 14½ ft. and there was no
visible reaction in the ladle when the steel was poured into the
slag. The fire-brick lining of the ladle and the stopper were
coated with magnesia cement.

The treated steel was cast through a 40-mm. (1$\frac{9}{16}$-in.) dia.
nozzle into open wide-end-up moulds, eight ingots of 1600 kg.
(32 cwt.) each being cast. After teeming, there was a skull weigh-
ing about 500 kg. (½ ton) left in the ladle bottom.

A sample of steel was taken for analysis after casting the fourth
ingot, and a sample of slag immediately after all the steel was cast.

The quantity of aluminium added in the moulds was 2 kg.
(4·4 lb.) to the first two ingots, which rose in the moulds, and 2½ kg.
(5·5 lb.) to the other six ingots, which had flat tops.

The following are the analyses of the steel and slag samples :

Analysis of Steel.

		Before Mixing.	After Mixing.
C. %	. . . . .	0·04	0·05
Mn. %	. . . . .	0·04	0·03
S. %	. . . . .	0·013	0·013
P. %	. . . . .	0·252	0·066
Si. %	. . . . .	0·005	0·002

Analysis of Slag.

						Before Mixing.	After Mixing.
SiO_2.	% .	•	•	•	•	4·75	5·36
Al_2O_3.	%	•	•	•	•	1·36	1·28
FeO.	% .	•	•	•	•	25·80	29·96
Fe_2O_3.	%	•	•	•	•	16·02	8·54
MnO.	% .	•	•	•	•	1·74	1·79
CaO.	% .	•	•	•	•	46·98	46·95
MgO.	% .	•	•	•	•	2·48	3·60
P_2O_5.	% .	•	•	•	•	0·19	2·03
TiO_2.	% .	•	•	•	•	Traces	Traces
S.	%	•	•	•	•	0·045	0·053

Notes on the Experiment.

(1) The phosphorus content of the steel before dephosphorising was found on analysis to be only 0·252% and not 0·30% as desired for the experiment.

(2) The phosphorus in the treated steel was 0·066% and, therefore, was not reduced below 0·050% as desired.

(3) The weight of the synthetic slag used was 15% of that of the steel plus the ladle skull, and was therefore much in excess of the amount regarded as necessary to effect the desired dephosphorisation.

(4) Although phosphorus had been removed to the extent of 0·186% (from 0·252 to 0·066%), the P_2O_5 content of the slag after mixing was only 2·03%, mainly due to the large percentage of dephosphorising slag used.

(5) The weight of ingots made was 12,800 kg. (12 tons 16 cwt.), whereas the total metallic charge was 12,150 kg. (12 tons 3 cwt.). Therefore, there was a gain of 650 kg. (13 cwt.), which can only be accounted for by some of the melted Armco iron from the slag furnace having been poured into the casting ladle with the synthetic slag.

(6) The CaO in the synthetic dephosphorising slag was only about 47% instead of 60% as desired. It was evident that the low lime content and high iron oxide content of the slag were brought about by dilution with some oxidised Armco iron charged in the slag furnace.

(7) There was very little decrease in the total iron oxide content of the slag after mixing, which was contrary to expectation.

(8) The treated steel was highly oxidised, as was evident from the fact that as much as 3·44 lb. of aluminium per ton was required to kill the steel in the moulds.

(B) DEPHOSPHORISING EXPERIMENT WITH 0·40% OF MANGANESE IN THE STEEL.

An experiment in the presence of so much manganese had never been attempted before by Mr. Perrin. As there was every possibility of the manganese being oxidised along with the phosphorus during the mixing of the steel and slag, if a slag of com-

position similar to that in the previous experiment were used, it was agreed that an addition of about 10% of MnO should be made to the slag for the present experiment, with the object of minimising the oxidation of manganese from the steel. As in the previous experiment, ferro-phosphorus would be added to yield about 0·30% of phosphorus in the steel, but in addition, ferro-manganese would be added to yield about 0·40% of manganese.

The object of this experiment was to ascertain whether it would be possible to make low-carbon steels direct from the acid Bessemer converter, by blowing the carbon out of Tata blast-furnace iron until only about 0·10% remained, adding the required amount of ferro-manganese in the converter, and then removing the phosphorus by pouring the blown metal containing manganese into a previously prepared synthetic slag.

Preparation of the Dephosphorising Slag.

As in the former dephosphorising experiment, a synthetic slag was prepared in the 5-ton basic electric furnace.

On the bottom of the furnace 2500 kg. (2½ tons) of Armco iron, and 1000 kg. (1 ton) of 12% manganese steel scrap were charged. The latter was added with the object of producing MnO in the slag, so as to minimise the oxidation of manganese from the steel during the mixing with the synthetic slag in the casting ladle.

The mixture of Armco iron and manganese steel scrap was allowed to melt, after which the following slag ingredients were charged in the furnace :

			Kg.	(Cwt.).
Lime (CaO 85%)	.	.	1400	(28)
Manganese ore (MnO 65%) .		.	400	(8)
Iron ore (FeO 65%) .	.	.	400	(8)
Fluorspar (CaF₂ 85%)	.	.	175	(3½)

Preparation of the Steel for Dephosphorising.

In the adjacent 15-ton basic electric furnace a charge consisting of 12,000 kg. (12 tons) of plain carbon-steel bloom butts and turnings was melted with 500 kg. (½ ton) of calcined lime. After the bath was clear melted, the slag was poured off. The following is a record of the heat from this stage :

Heat No. 92,467.   10th October, 1935.

								P.M.
First slag poured off	.	.	.	.	.	.	.	4.36–4.40
Lime added to clean bath (200 kg. (4 cwt.))	.	.	.				.	4.43
All slag raked off	.	.	.	.	.	.	.	4.53–5.00
Ferro-manganese added, C 6%, Mn 80% (58 kg. (1·16 cwt.))						.		5.01
Ferro-phosphorus added, P 24%, Si 5% (150 kg. (3 cwt.))						.		5.02
Sample of steel .	.	.	.	.	.	.	.	5.05
Furnace tapped (steel poured into slag) .		.	.	.	.	.	.	5.06

Slag Furnace.

Sample of slag .	.	.	.	.	.	.	.	.	4.59
Slag tapped into casting ladle (2000 kg. (2 tons))			.		.		.		5.04

The pouring height from the furnace launder to the bottom of the casting ladle was about $14\frac{1}{2}$ ft., and there was only a mild reaction discernible in the ladle when the steel was poured into the slag.   The firebrick lining of the ladle and the stopper were coated with magnesia cement.

The treated steel was cast through a 40-mm. ($1\frac{9}{16}$-in.) dia. nozzle into wide-end-up moulds.   Nine ingots of 1600 kg. (32 cwt.) each without hot tops, and two ingots of 500 kg. (10 cwt.) each with hot tops were made.   The two small ingots were cast into moulds with hot tops because there was much more steel than expected and no other moulds were available without hot tops.   After teeming, there was a skull weighing about 200 kg. (4 cwt.) left in the ladle bottom.

A sample of steel was taken for analysis after casting the fourth ingot, and a sample of slag immediately after all the steel was cast.

In the moulds an addition of 2 kg. (4·4 lb.) of aluminium plus $2\frac{1}{2}$ kg. (5·5 lb.) of silicon-aluminium alloy (Si 35%, Al 45%) was made to each ingot weighing 1600 kg. (32 cwt.), and $1\frac{1}{4}$ kg. (2·75 lb.) of aluminium to each ingot weighing 500 kg. ($\frac{1}{2}$ ton).   The larger ingots had flat tops, while the smaller ingots cast with hot tops had sunken heads.

The following are the analyses of the steel and slag samples :

Analysis of Steel.

					Before Mixing.	After Mixing.
C. %	.	.	.	.	0·08	0·07
Mn. %	.	.	.	.	0·42	0·26
S. %	.	.	.	.	0·029	0·016
P. %	.	.	.	.	0·253	0·076
Si. %	.	.	.	.	Nil	0·003

Analysis of Slag.

					Before Mixing.	After Mixing.
SiO_2. %	.	.	.	.	6·86	8·98
Al_2O_3. %	.	.	.	.	1·24	1·94
FeO. %	.	.	.	.	12·87	18·70
Fe_2O_3. %	.	.	.	.	14·54	5·98
MnO. %	.	.	.	.	10·42	11·08
CaO. %	.	.	.	.	51·65	47·55
MgO. %	.	.	.	.	1·56	2·58
P_2O_5. %	.	.	.	.	0·22	2·38
TiO_2. %	.	.	.	.	Traces	Traces
S. %	.	.	.	.	0·048	0·081

Notes on the Experiment.

(1) As in the previous experiment, the phosphorus content of the steel before mixing with the slag was found on analysis to be low, being 0·253% against 0·30% desired.

(2) The phosphorus in the treated steel was 0·076% and, therefore, was not reduced below 0·050% as desired.

(3) The weight of synthetic slag used was nearly 13% of the weight of steel plus the ladle skull.

(4) Although phosphorus had been removed to the extent of 0·177% (from 0·253 to 0·076%), the P_2O_5 content of the slag after mixing was only 2·38%, mainly owing to the large percentage of dephosphorising slag used.

(5) The presence of more than 10% of MnO in the slag did not prevent the oxidation of some of the manganese, which was reduced from 0·42% to 0·26% during the dephosphorising reaction.

(6) The weight of ingots made was 15,400 kg. (15 tons 8 cwt.), whereas the total metallic weight charged was 12,208 kg. (12 tons 4 cwt.). Therefore, there was a gain of about 3200 kg. (3 tons 4 cwt.), so that it is certain that the whole of the Armco iron and manganese steel scrap was melted and tapped into the casting ladle along with the dephosphorising slag.

(7) The CaO in the synthetic slag was 51·65%, which was more than in the previous experiment, but still lower than desired. This was evidently due to dilution with some oxidised Armco iron and manganese-steel scrap charged in the slag furnace.

(8) As in the former experiment, there was very little reduction in the total iron content of the slag after mixing.

(9) The treated steel was highly oxidised, as indicated by the large additions of aluminium (2·75 lb. per ton) plus silicon-aluminium alloy (3·44 lb. per ton) which were required to kill the steel in the moulds.

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Although the two foregoing experiments in dephosphorisation carried out at the Ugine steelworks were only partly successful and left much to be desired, they were considered by Mr. Ghandy and the author to be sufficiently encouraging to justify the conducting of further experiments at the Tata Works in India.

The result was that upon the author's return to India, an exhaustive series of experiments was carried out under his supervision at the Tata duplex plant, as circumstances permitted. In all, one hundred experiments were conducted, of which particulars of a selection are contained in the following pages.

EXPERIMENTS ON THE DEPHOSPHORISATION OF STEEL WITH A SYNTHETIC SLAG AT THE TATA IRON AND STEEL WORKS, INDIA.

In order to conduct these experiments, one of the 250-ton basic open-hearth tilting furnaces at the duplex plant was employed for melting the synthetic dephosphorising slag whenever suitable opportunities occurred.

It was decided that the experiments, to commence with, would be conducted on similar lines to those carried out at the Ugine

steelworks, France. Therefore, blast-furnace iron taken from the hot-metal mixer would be blown in an acid Bessemer converter, after which the blown metal would be poured into a quantity of synthetic molten slag in the casting ladle, and the resultant dephosphorised steel cast into ingots.

Owing to a difference in gauges of the overhead ladle cranes in the Bessemer shop and the open-hearth pitside, and the pouring height from the Bessemer converters being insufficient, it was not possible to carry out the experiments without reladling the blown metal. Therefore, it was necessary to provide a firebrick-lined pouring trough leading from the furnace platform to the pitside, so that blown metal could be poured down the trough into the dephosphorising slag contained in a pitside casting ladle, which was being held in the hooks of one of the pitside ladle cranes. The height of the trough from the bottom of the casting ladle was $21\frac{1}{2}$ ft. This arrangement, of course, resulted in a loss of temperature of the blown metal, so that, to provide for this loss, a higher silicon content of the iron was essential than would be required in a new plant specially designed for operating the Perrin process, where reladling would be totally unnecessary. It was also necessary to use ladles of 100-ton capacity in all the experiments, as smaller ladles were unavailable. The following are particulars of a selection of experiments carried out at the Tata Works.

(A) Dephosphorising Experiment with Very Low Percentage of Manganese in the Bessemer Blown Metal.

Heat No. P2.   11th November, 1935.

The object of this experiment was to dephosphorise a Bessemer soft blow without any manganese addition. This experiment therefore was similar to Mr. Perrin's first experiment at Ugine.

Preparation of the Dephosphorising Slag.

In order to provide sufficient slag for a number of experiments, the following ingredients were charged and melted in one of the duplex basic open-hearth furnaces :

	Ton. Cwt.	SiO_2. %.	Fe_2O_3. %.	Al_2O_3. %.	CaO. %.	MgO. %.	Loss. %.
				Composition.			
Calcined lime	13 0	5·28	1·34	1·02	86·29	2·56	3·26 Moisture.
Iron ore	7 0		Fe. %. 62·39				1·05
Fluorspar	1 12	SiO_2. %. 5·01			CaF_2. %. 90·00		
Total	21 12						

Details of the Experiment.

Weight of iron blown . . 25 tons 2 cwt.
Bessemer blow number . . 37,598
Duration of blow . . . 12.19–12.35 P.M. (16 min.).
Weight of slag poured into cast-
   ing ladle . . . . 2 tons 5 cwt.
Time slag poured into casting
   ladle . . . . 12.40 P.M.
Time blown metal poured down
   trough into casting ladle . 12.42–12.45 P.M.
Reaction in casting ladle . Very violent, persisted for 5 min. after
   all blown metal had been poured.
Started casting ingots . . 12.50 P.M.
Finished casting ingots . . 1.02 P.M.
Dia. of nozzle . . . $1\frac{3}{4}$ in.
Ladle . . . . . A 100-ton casting ladle was used in
   this experiment. The bottom and 7
   courses were of magnesite bricks,
   remainder firebricks. The fireclay
   stopper was coated with magnesite
   paste.
Weight of ingots cast . . 22 tons 4 cwt.
   5 ingots were cast in narrow-end-up
   moulds and were allowed to rim
   without any aluminium additions being
   made. All the ingots were of the
   box-hat type.
Ladle skull . . . . 15 cwt.

Analysis of Metal Samples.

	C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron . . .	...	0·38	0·025	0·292	1·22
Blown metal from converter .	0·16	0·08	0·026	0·250	0·030
Pitside ladle samples after dephosphoris- ing — Ingot No. 1	0·08	0·04	0·031	0·018	0·032
Ingot No. 3	0·07	...	...	0·018	...

Analysis of Slag Samples.

	Before Mixing.	After Mixing.
SiO_2. %	6·50	18·00
Al_2O_3. %	1·50	3·04
FeO. %	17·80	21·15
Fe_2O_3. %	22·18	4·58
MnO. %	0·40	2·48
CaO. %	47·85	41·35
MgO. %	3·32	2·95
P_2O_5. %	0·51	5·75
TiO_2. %	Nil	0·55
S. %	0·06	0·08

Notes on the Experiment.

(1) The dephosphorisation was very intensive, the phosphorus being eliminated to such an extent that only 0·018% remained in the finished steel after mixing. Thus with a slag of somewhat similar composition to that used in the first experiment at the Ugine steelworks, also containing less than 50% of lime, a much

more satisfactory degree of dephosphorisation was effected in this experiment. This can be attributed to the 50% greater pouring height in the present experiment and to the violent reaction which occurred in the casting ladle and churned up the slag and blown metal together, owing to the presence of $0\cdot16\%$ of carbon in the blown metal.

(2) It is interesting to note that the phosphorus in the original iron was decreased from $0\cdot292$ to $0\cdot250\%$ during the blow in the acid Bessemer converter, despite the loss of about 10% of metal owing to oxidation of elements. A loss of phosphorus at this stage, possibly caused by volatilisation, persisted throughout the experiments, and is a daily occurrence in the blowing of iron for the duplex process.[1] The weight of synthetic slag used was about 10% of the weight of the steel ingots plus ladle skull. The P_2O_5 in the slag after dephosphorisation was $5\cdot75\%$. On account of the loss of phosphorus during the blow, it did not seem possible— even with the use of only 7% of slag—to obtain a sufficiently high percentage of P_2O_5 in the finished slag to make it of any value as an artificial fertiliser.

(3) The large increase in the SiO_2 content of the slag was due to a considerable quantity of acid converter slag having entered the casting ladle along with the blown metal. As will be seen later, this occurred in all the experiments, but did not affect the dephosphorisation.

(4) There was a marked reduction in the total iron oxide $(FeO + Fe_2O_3)$ content of the slag after mixing. It is of interest to note, however, that the Fe_2O_3 decreased while the FeO increased. This also occurred in all the experiments in which a synthetic slag was used.

(5) In contrast with the killed steel ingots cast at the Ugine steelworks, the ingots made in this experiment were purposely allowed to rim without aluminium additions. As stated, these ingots were of the box-hat type, thus indicating the necessity of adding a little aluminium in the moulds to cause the ingots to rim in level with the pouring height.

(B) DEPHOSPHORISING EXPERIMENTS WITH MANGANESE ADDED TO THE BESSEMER BLOWN METAL.

Heat No. P3. 11th November, 1935.

The object of this experiment was to dephosphorise a Bessemer soft blow to which manganese had been added, and to retain as much as possible of the added manganese. This experiment, therefore, was similar to Mr. Perrin's second experiment at Ugine.

[1] This phenomenon has been commented upon before by the author in his previous paper (loc. cit.).

Preparation of the Dephosphorising Slag.

In the previous experiment described 2 tons 5 cwt. of slag were used out of a total of 21 tons 12 cwt., leaving a balance in the furnace of 19 tons 7 cwt. To this remaining quantity of slag were added 3 tons 3 cwt. of manganese ore of the following composition :

Mn. %.	Fe. %.	P. %.	Insoluble Matter. %.
42·94	12·20	0·095	7·59

The manganese ore was added to yield MnO in the slag with the object of protecting the manganese in the blown metal from excessive oxidation during the reaction with the synthetic slag.

Details of the Experiment.

Weight of iron blown . .	21 tons 10 cwt.
Bessemer blow number . .	37,609
Duration of blow . . .	4.59–5.12 P.M. (13 min.).
Ferro-manganese (Mn 73·5%) added in converter ladle to blown metal . . .	448 lb.
Weight of slag poured into casting ladle	2 tons 15 cwt.
Time slag poured into casting ladle	5.20 P.M.
Time blown metal poured down trough into casting ladle .	5.22–5.23 P.M.
Reaction in casting ladle .	Very violent, but subsided in 2 min.
Started casting ingots . .	5.25 P.M.
Finished casting ingots . .	5.35 P.M.
Dia. of nozzle . . .	1¾ in.
Ladle	A 100-ton casting ladle was used lined throughout with firebrick. The fireclay stopper was not coated with basic cement.
Weight of ingots cast . .	19 tons 10 cwt.
	4 ingots were cast in narrow-end-up moulds and were allowed to rim. No aluminium was added to the first ingot, which was of the box-hat type. 2 oz. of aluminium were added to each of the remaining 3 ingots, which rimmed in level and were subsequently capped.
Ladle skull	15 cwt.

Analysis of Metal Samples.

	C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron . . .	...	0·35	0·023	0·290	1·41
Blown metal from converter .	0·09	0·08	0·024	0·250	0·061
Blown metal after addition of ferro-manganese . . .	0·11	0·60	...	...	...
Pitside ladle samples after dephosphorising { Ingot No. 1	0·04	0·15	0·023	0·017	0·024
{ Ingot No. 3	0·04	0·14	...	0·018	...

Analysis of Slag Samples.

			Before Mixing.	After Mixing.
SiO_2.	%		6·56	19·47
Al_2O_3.	%		1·47	5·37
FeO.	%		8·23	16·77
Fe_2O_3.	%		28·70	5·43
MnO.	%		7·95	10·66
CaO.	%		42·65	35·20
MgO.	%		2·91	2·52
P_2O_5.	%		0·58	3·13
TiO_2.	%		Nil	0·62
S.	%		Trace	Trace

Notes on the Experiment.

(1) In this experiment an acid-lined ladle was used, but this did not affect the dephosphorisation, which was just as intensive as in the previous experiment, heat No. *P2.* Moreover, the erosion of the firebrick lining during the mixing was negligible.

(2) The dephosphorisation also took place in the presence of nearly 8% of MnO in the slag, which, however, was lower by nearly 2·5% than in the slag employed in the second experiment carried out at the Ugine steelworks. Despite the presence of this MnO in the slag, the manganese in the steel was oxidised from 0·60 to 0·15%, thus indicating that there was insufficient MnO in the synthetic slag to prevent the excessive oxidation of manganese. The weight of ferro-manganese (73·5% Mn) added to the blown metal was 448 lb., yielding 329 lb. of manganese, which was 0·72% on the gross metallic yield (weight of ingots + ladle skull), and 0·08% of residual manganese added to this made a total of 0·80%. Therefore, the actual loss of manganese in this experiment was 0·80 − 0·15 = 0·65%, which was more than 80% of the total manganese.

(3) It should be noted that notwithstanding the comparatively low percentage of CaO in the slag (42·65%), the removal of phosphorus was very satisfactory.

(4) The quantity of synthetic slag used was excessive, being about $13\frac{1}{2}$% of the weight of the ingots plus ladle skull.

(5) The ingots cast were allowed to rim, the first ingot, to which no aluminium was added, being of the box-hat type, while the remaining three ingots, to each of which 2 oz. of aluminium were added, rimmed in level with the pouring height.

Heat No. P6. 12th *November,* 1935.

This experiment was a repetition of heat No. *P3,* but with a larger percentage of MnO in the slag.

Preparation of the Dephosphorising Slag.

Extra manganese ore was added to the slag in the open-hearth melting furnace, with the object of increasing the MnO content of the slag by about 2%, *i.e.,* from about 8% in the slag used in

heat No. *P*3, to about 10% in the present slag, so that it would
be similar in MnO content to the slag employed in Mr. Perrin's
second experiment at the Ugine steelworks.

Details of the Experiment.

Weight of iron blown . .	25 tons 15 cwt.
Bessemer blow number . .	37,706
Duration of blow . . .	2.30–2.45 P.M. (15 min.).
Ferro-manganese (Mn 73·5%) added in converter ladle to blown metal . . .	448 lb.
Weight of slag poured into casting ladle	2 tons.
Time slag poured into casting ladle	2.54 P.M.
Time blown metal poured down trough into casting ladle .	2.57–2.59 P.M.
Reaction in casting ladle .	Extremely violent, persisting for 5 min.
Started casting ingots . .	3.04 P.M.
Finished casting ingots .	3.17 P.M.
Dia. of nozzle . . .	1¾ in.
Ladle	A 100-ton casting ladle was used. The bottom and 7 courses were of magnesite bricks, remainder firebricks. The fireclay stopper was coated with magnesite paste.
Weight of ingots cast . .	23 tons 6 cwt.
	5 ingots were cast in narrow-end-up moulds. The ingots were allowed to rim, and all of them rose about 3 in. in the moulds above the pouring height. No aluminium was added. The ingots were capped.
Ladle skull	5 cwt.

Analysis of Metal Samples.

	C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron . . .	...	0·35	0·017	0·280	1·41
Blown metal from converter .	0·15	0·17	0·020	0·252	0·047
Blown metal after addition of ferro-manganese . . .	0·21	0·69	...	...	...
Pitside ladle samples after dephosphorising ⎰ Ingot No. 1	0·17	0·52	0·016	0·039	0·008
⎱ Ingot No. 3	0·15	0·50	...	0·035	...

Analysis of Slag Samples.

		Before Mixing.	After Mixing.
SiO_2.	%	7·62	18·64
Al_2O_3.	%	1·59	2·72
FeO.	%	2·06	11·35
Fe_2O_3.	%	27·57	4·43
MnO.	%	10·47	13·76
CaO.	%	45·30	43·00
MgO.	%	4·89	2·74
P_2O_5.	%	0·45	3·82
TiO_2.	%	Nil	Trace
S.	%	Trace	0·06

Notes on the Experiment.

(1) In this experiment the MnO content of the synthetic slag was about $10\frac{1}{2}\%$, thus being about the same as in the second experiment at Ugine, compared with about 8% in the previous experiment, heat No. *P*3. The dephosphorisation was quite satisfactory and at the same time 0.51% of manganese was retained in the steel. The ferro-manganese (Mn 73.5%) added to the blown metal was 448 lb. as in heat No. *P*3, yielding 329 lb. of manganese, which was 0.62% on the gross metallic yield. The residual manganese in the blown metal was 0.17%, making a total of 0.79% of manganese. Of this 0.51% was retained in the finished steel, so that the total loss of manganese was 0.28% ($0.79 - 0.51\%$), which was about 35% of the total manganese, compared with a little over 80% loss in the previous experiment, heat No. *P*3.

(2) In addition to the higher percentage of MnO in the slag in this experiment, as compared with heat No. *P*3, it was considered possible that the higher percentage of carbon in the blown metal might have had some influence on the retention of so much manganese after mixing.

(3) The weight of synthetic slag used in this experiment was about $8\frac{1}{2}\%$, which was considerably lower than in heat No. *P*3, in which about $13\frac{1}{2}\%$ of slag were employed.

(4) The ingots were successfully rolled into 8-in. square blooms, and then into 2-in. square billets for the merchant mill, where they were finally rolled into $\frac{1}{2}$-in. dia. rounds.

Heat No. P7. 12*th November*, 1935.

The object of this experiment was to repeat heat No. *P*6, but with a still higher percentage of MnO in the slag, and a lower percentage of carbon in the blown metal.

Preparation of the Dephosphorising Slag.

A further addition of manganese ore was made to the slag used in the last experiment so as to increase the MnO by another 2%.

Details of the Experiment.

Weight of iron blown . .	25 tons 15 cwt.
Bessemer blow number . .	37,710
Duration of blow . . .	3.51–4.06 P.M. (15 min.).
Ferro-manganese (Mn 73.5%) added in converter ladle to blown metal . . .	448 lb.
Weight of slag poured into casting ladle	2 tons.
Time slag poured into casting ladle	4.08 P.M.
Time blown metal poured down trough into casting ladle .	4.10–4.12 P.M.
Reaction in casting ladle .	Not so violent as in heat No. *P*6, subsided in 2 min.
Started casting ingots . .	4.14 P.M.

E

Finished casting ingots . . 4.26 P.M.
Dia. of nozzle . . . 1¾ in.
Ladle . . . . . As in heat No. P6.
Weight of ingots cast . . 23 tons 2 cwt.
                                5 ingots were cast in narrow-end-up
                                moulds. The ingots were allowed to
                                rim. 2 oz. of aluminium were added
                                in each mould. All the ingots rimmed
                                in level and were capped.
Ladle skull . . . . 5 cwt.

Analysis of Metal Samples.

	C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron . . .	...	0·35	0·017	0·280	1·41
Blown metal from converter .	0·07	0·08	0·020	0·268	0·055
Blown metal after addition of ferro-manganese . . .	0·12	0·45	...	...	...
Pitside ladle samples after dephosphoris-ing Ingot No. 1	0·05	0·22	0·019	0·034	0·004
Ingot No. 3	0·04	0·20	...	0·032	...

Analysis of Slag Samples.

	Before Mixing.	After Mixing.
SiO₂. %	7·75	19·22
Al₂O₃. %	0·67	2·38
FeO. %	3·48	12·00
Fe₂O₃. %	27·14	8·86
MnO. %	12·64	14·44
CaO. %	44·20	36·40
MgO. %	2·77	2·38
P₂O₅. %	0·62	4·63
TiO₂. %	Trace	Trace
S. %	0·04	0·05

Notes on the Experiment.

(1) In this experiment the carbon in the blown metal was 0·07%, compared with 0·15% in heat No. P6. The dephosphorisation was again quite successful. Despite the presence of 2% more MnO in the slag, much more manganese was lost than in the previous experiment, for only 0·21% of this element was retained in the finished steel. The total loss of manganese in this experiment was 70%. The result, therefore, indicated that still more MnO was required in the slag to protect the manganese from being oxidised excessively.

(2) The same weight of blast-furnace iron and synthetic slag was used in this experiment as in heat No. P6, for comparative purposes, but the results obtained were very dissimilar, evidently owing to the lower carbon content of the blown metal in this experiment.

Heat No. P8. *12th November,* 1935.

The object of this experiment was to dephosphorise two Bessemer blows doubled together in one ladle and to cast steel ingots to the following chemical specification :

C. %.   Mn. %.   P and S. %.
0·10–0·14   0·30–0·50   0·050 max.

Preparation of the Dephosphorising Slag.

A further addition of manganese ore was added to the synthetic slag to increase the MnO content to about 15%.

Details of the Experiment.

Weight of iron blown . .	48 tons
Bessemer blow numbers . .	$\begin{cases} 37{,}712 \\ 37{,}713 \end{cases}$
Duration of blows . . .	$\begin{cases} 4.45\text{--}4.59 \text{ P.M. (14 min.).} \\ 4.54\text{--}5.11 \text{ P.M. (17 min.).} \end{cases}$
Ferro-manganese (Mn 73·5%) added in converter ladle to blown metal . . .	896 lb.
Weight of slag poured into casting ladle	4 tons.
Time slag poured into casting ladle	5.18 P.M.
Time blown metal poured down trough into casting ladle .	5.19–5.21 P.M.
Reaction in casting ladle .	Very violent, persisted for 4 min. During the reaction slag rose to the top of the casting ladle and overflowed a little.
Started casting ingots . .	5.25 P.M.
Finished casting ingots . .	5.44 P.M.
Dia. of nozzle . . .	$1\frac{3}{4}$ in.
Ladle	As in heat No. $P6$.
Weight of ingots cast . .	43 tons 4 cwt.
	9 ingots were cast in narrow-end-up moulds. The ingots were allowed to rim. 2 oz. of aluminium were added in each mould. All the ingots rimmed in level and were capped.
Ladle skull	12 cwt.

Analysis of Metal Samples.

	C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron . . .	...	0·35	0·017	0·280	1·41
Blown metal from 1st blow .	0·17	0·10	0·018	0·255	0·046
each converter 2nd blow .	0·04	0·05	0·017	0·274	0·038
Blown metal after addition of ferro-manganese Double blow .	0·16	0·51	...	...	...
Pitside ladle samples after dephosphoris-ing Ingot No. 1	0·13	0·28	0·013	0·018	0·007
Ingot No. 4	0·11	0·28	...	0·016	...

Analysis of Slag Samples.

		Before Mixing.	After Mixing.
SiO₂.	%	8·80	16·50
Al₂O₃.	%	0·67	0·62
FeO.	%	2·97	3·10
Fe₂O₃.	%	24·86	16·58
MnO.	%	15·48	17·16
CaO.	%	44·20	39·00
MgO.	%	2·53	2·16
P₂O₅.	%	0·30	4·81
TiO₂.	%	Nil	Trace
S.	%	Trace	0·04

Notes on the Experiment.

(1) In this experiment the dephosphorisation of a double blow from the Bessemer converters was carried out successfully. So far as the author is aware, this was the first occasion on which such a large quantity of steel had been dephosphorised in the ladle. Although the slag contained about $15\frac{1}{2}\%$ of MnO, there was a large amount of manganese oxidised from the steel, resulting in this element finishing at $0\cdot28\%$, which was on the low side of the specification of $0\cdot30\text{–}0\cdot50\%$ aimed at. The total loss of manganese in this experiment worked out at 62%.

(2) The weight of synthetic slag used was a little over 9%.

(3) The ingots were successfully rolled into 8-in. square blooms and then into 2-in. square billets for the merchant mill, where they were finally rolled into $\frac{1}{2}$-in. dia. rounds.

Heat No. P15.   27th November, 1935.

This experiment was similar to No. *P*8 and was made to compare the results of that experiment with the present results. Therefore, two Bessemer blows were again dephosphorised, and another attempt was made to cast steel ingots to the same chemical specification as that aimed at in heat No. *P*8.

Preparation of the Dephosphorising Slag.

For this experiment manganese ore was added to the slag to yield a higher MnO content than in any of the previous experiments, $17\frac{1}{2}\%$ of MnO being desired.

Details of the Experiment.

Weight of iron blown . .	47 tons.
Bessemer blow numbers . .	$\begin{cases} 38,910 \\ 38,911 \end{cases}$
Duration of blows . . .	$\begin{cases} 11.24\text{–}11.39 \text{ A.M. } (15 \text{ min.}). \\ 11.35\text{–}11.50 \text{ A.M. } (15 \text{ min.}). \end{cases}$
Ferro-manganese (Mn $73\cdot5\%$) added in converter ladle to blown metal . . .	896 lb.
Weight of slag poured into casting ladle	4 tons.
Time slag poured into casting ladle	12.03 P.M.
Time blown metal poured down trough into casting ladle .	12.06–12.10 P.M.
Reaction in casting ladle .	Very violent, persisted for 5 min. The blown metal was poured more slowly into the slag than in heat No. *P*8, and therefore did not overflow the ladle.
Started casting ingots . .	12.15 P.M.
Finished casting ingots . .	12.38 P.M.
Dia. of nozzle . . .	$1\frac{3}{4}$ in.
Ladle	A 100-ton casting ladle was used, lined throughout with firebrick. The fireclay stopper was coated with magnesite paste.

Weight of ingots cast . . 42 tons.
9 ingots were cast in narrow-end-up moulds. The ingots were allowed to rim. 2 oz. of aluminium were added in each mould. All the ingots rimmed in level and were capped.

Ladle skull . . . . 1 ton.

Analysis of Metal Samples.

		C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron	. . .	...	0·48	0·035	0·280	1·35
Blown metal from each converter {	1st blow .	0·09	0·07	...	...	...
	2nd blow .	0·08	0·07	...	...	...
Blown metal after addition of ferro-manganese {	Double blow	0·11	0·43	...	0·268	0·023
Pitside ladle samples after dephosphoris-ing {	Ingot No. 1	0·07	0·28	0·023	0·017	Nil
	Ingot No. 5	0·06	0·28	...	0·018	...

Analysis of Slag Samples.

						Before Mixing.	After Mixing.
SiO_2.	% .	.	.	.	.	9·14	17·96
Al_2O_3.	% .	.	.	.	.	1·00	4·52
FeO.	% .	.	.	.	.	0·90	12·38
Fe_2O_3.	% .	.	.	.	.	19·00	5·29
MnO.	% .	.	.	.	.	17·03	16·88
CaO.	% .	.	.	.	.	47·40	36·60
MgO.	% .	.	.	.	.	4·96	3·02
P_2O_5.	% .	.	.	.	.	0·28	2·59
TiO_2.	% .	.	.	.	.	Trace	0·60
S.	%	.	.	.	.	Trace	0·064

Notes on the Experiment.

(1) As in heat No. P8, the dephosphorisation of a double blow from the Bessemer converters was successfully accomplished. However, the manganese in the steel again finished on the low side of the specification (0·28%), despite the presence of 17% of MnO in the slag. The total loss of manganese was 62%, thus being the same as in heat No. P8. The carbon also finished low in this experiment.

(2) The weight of synthetic slag used was the same as in heat No. P8, that is, a little over 9%.

(3) The ingots were successfully rolled into 8-in. square blooms and then into 2-in. square billets for the merchant mill, where they were subsequently rolled into ½-in. dia. rounds.

(C) *Experiments on the Method of Adding Ferro-Manganese.*

The foregoing experiments showed clearly that although the blown metal could be successfully and rapidly dephosphorised by the Perrin process, the results, as far as carbon and manganese were concerned, were much too inconsistent, so that it did not

appear possible to guarantee the manufacture of steel to chemical specification by the method so far tried out.

Therefore, the author decided to conduct a series of experiments with the object of discovering the most satisfactory method of adding manganese to the steel, at the same time observing the following essential conditions :

(*a*) Maintenance of sufficient control over the percentage of manganese introduced into the steel to enable the latter to be manufactured regularly to chemical specification ;

(*b*) Obtainment of uniform composition throughout the whole cast ;

(*c*) Prevention of rephosphorisation of the steel.

The following are the various methods of adding manganese to the steel which were tried, with comments on the results obtained.

(1) *Ferro-Manganese Added Cold to the Blown Metal before Dephosphorising.*

In addition to experiments Nos. *P*3, *P*6, *P*7, *P*8 and *P*15, of which particulars have already been given, a few more experiments on this method of adding manganese were carried out. Similar unreliable results were obtained, and control of the analysis was found to be impossible, the manganese in the finished steel in all the experiments under this heading varying from 0.14 to 0.51%. Except in the case of heat No. *P*6, excessive oxidation of manganese was the result, even in the presence of at least 15% of MnO in the slag, which, of course, necessitated the addition of a considerable quantity of manganese ore to the slag—a costly procedure. Therefore, this method was considered to be entirely unsatisfactory.

(2) *Ferro-Manganese Added in a Molten State to the Dephosphorised Blown Metal through the Slag.*

The result of an experiment on this method of adding manganese was remarkable in that the whole of the added manganese was abstracted by the synthetic slag, notwithstanding the presence of 9.6% of MnO in the slag. Sufficient molten ferro-manganese was added to yield normally 0.40% of manganese in the finished steel, but only 0.10% was found in the pitside ladle samples on analysis, which was about the same percentage of manganese as was present in the dephosphorised blown metal before the addition of the molten ferro-manganese. Moreover, rephosphorisation occurred, for, whereas the phosphorus in the dephosphorised blown metal was 0.031%, as much as 0.105% of phosphorus was found in the finished steel. This method, therefore, was ruled out of further consideration.

(3) *Ferro-Manganese Added Cold to the Dephosphorised Blown Metal, after Pouring off the Dephosphorising Slag.*

This method was found to be successful so far as the introduction of manganese to the steel was concerned, for the analysis of the finished steel was found to be uniform throughout the cast, ladle samples, taken when casting each ingot, having carbon and manganese contents between the limits of $0\cdot09$–$0\cdot10\%$ and $0\cdot47$–$0\cdot49\%$ respectively. The loss of manganese was a little over 40%.

The objection to this method, however, was that the steel in the casting ladle skulled badly, so that the ingots did not cast satisfactorily, owing to the loss of temperature incurred during the time taken to pour off the slag after dephosphorisation and to the absence of a sufficient quantity of hot slag covering the steel in the ladle during the casting of the ingots.

(4) *Ferro-Manganese Added Cold to the Dephosphorised Blown Metal through the Slag.*

Two experiments on this method of adding manganese were tried out, and in each case the manganese content of the steel varied considerably throughout the cast and rephosphorisation occurred. The method was therefore considered to be unsatisfactory.

(5) *Ferro-Manganese Added Cold in the Ladle Bottom ; Dephosphorising Slag Poured on the Top of the Ferro-Manganese, and then the Blown Metal Poured into the Slag.*

An experiment under these conditions did not prove satisfactory inasmuch as there was an excessive loss of manganese in the slag, the MnO content of which rose from $2\cdot98$ to $8\cdot38\%$ after mixing. The manganese content of the steel also was not uniform, varying from $0\cdot19$ to $0\cdot30\%$ in the cast. After casting the steel into ingots, some of the ferro-manganese was found undissolved in the ladle bottom. This method was therefore ruled out as being unreliable and unsatisfactory.

(6) *Ferro-Manganese Added Red-Hot in the Ladle Bottom ; Dephosphorising Slag Poured on the Top of the Ferro-Manganese, and then the Blown Metal Poured into the Slag.*

The loss of manganese in this experiment was even greater than in the case of cold ferro-manganese (experiment (5)), evidently owing to the red-hot alloy being more readily dissolved by the molten synthetic slag, the MnO content of which rose from $2\cdot45$ to $10\cdot50\%$ after mixing. The manganese content of the steel also was not uniform, for it varied from $0\cdot10$ to $0\cdot26\%$ in the cast. After casting the steel into ingots there was no trace of unmelted ferro-manganese in the bottom of the casting ladle such as occurred

when the cold alloy was used (experiment (5)). This method was ruled out as being unreliable and unsatisfactory.

(7) *Ferro-Manganese Added Red-Hot to the Dephosphorised Blown Metal through the Slag.*

Several experiments in which the addition of red-hot lump ferro-manganese was made through the slag were conducted. The results were very consistent, and the composition of the finished steel was always within the chemical specification aimed at. The manganese was also found to be uniformly distributed throughout each cast and the loss of this element averaged about 35%.

In order to carry out these experiments, a roasting furnace fired by coke-oven gas for heating up the ferro-manganese to a red-hot condition was installed at the side of the blown-metal pouring trough on the furnace platform. The required weight of ferro-manganese in pieces of 3 to 4 in. in size was charged in the roasting furnace, which was tilted at an angle towards the pitside and had a chute attached which directed the alloy into the casting ladle. As soon as the dephosphorising reaction had subsided, the ferro-manganese lumps, which had been made red-hot in the meantime, were pushed with a rake down the chute and dumped into the casting ladle through the slag. Five minutes were allowed to elapse for the alloy to dissolve and the resultant steel was then cast into ingots. The following are particulars of two experiments conducted on these lines.

Heat No. P36.   21*st November,* 1936.

The object of this experiment was to dephosphorise two blows from the Bessemer converters, and to add manganese to the dephosphorised metal in order to cast steel ingots suitable for rolling into sheet bar, the chemical specification of which was as follows :

C. %.	Mn. %.	P. %.	S. %.
0·10–0·14	0·30–0·50	0·04–0·08	0·050 max.

Preparation of the Dephosphorising Slag.

For this and other experiments, the following slag ingredients were charged on the top of about 30 tons of molten metal left in the 250-ton open-hearth furnace from the last heat tapped :

	Tons. Cwt.	SiO_2. %.	Fe_2O_3. %.	Al_2O_3. %.	CaO. %.	MgO. %.	Loss. %.
				Composition.			
Calcined lime	16 0	4·84	1·22	1·00	87·08	2·50	3·10
Mill scale	7 15						
		SiO_2. %.			CaF_2. %.		
Fluorspar.	1 5	5·57			91·75		
Total	25 0						

Details of the Experiment.

Weight of iron blown . .	44 tons.
Bessemer blow numbers . .	$\begin{cases} 70{,}485 \\ 70{,}486 \end{cases}$
Duration of blows . . .	$\begin{cases} 10.23\text{--}10.39 \text{ A.M. (16 min.).} \\ 10.27\text{--}10.42 \text{ A.M. (15 min.).} \end{cases}$
Weight of slag poured into casting ladle	3 tons.
Time slag poured into casting ladle	10.55–10.56 A.M.
Time blown metal poured down trough into casting ladle .	10.59–11.05 A.M.
Reaction in casting ladle .	Moderate, owing to slow pouring of metal. The reaction continued for 3 min.
750 lb. of ferro-manganese (Mn 75%) added red-hot in casting ladle as soon as dephosphorising reaction ceased . .	11.08 A.M.
Started casting ingots . .	11.13 A.M.
Finished casting ingots . .	11.31 A.M.
Dia. of nozzle . . .	$1\frac{3}{4}$ in.
Ladle	A 100-ton ladle was used, lined throughout with firebrick. The fireclay stopper was coated with chromite paste.
Weight of ingots cast . .	39 tons 17 cwt.
	8 ingots were cast in narrow-end-up moulds. The ingots were allowed to rim. 2 oz. of aluminium were added in each mould. All the ingots rimmed in level and were capped.
Ladle skull	10 cwt.

Analysis of Metal Samples.

		C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron	. . .	...	0·44	0·026	0·326	1·41
Blown metal from each converter	1st blow .	0·04	...	...	...	...
	2nd blow .	0·08	...	...	...	...
Blown metal before dephosphorising	Double blow	0·06	0·08	0·029	0·285	0·056
Pitside ladle samples after dephosphorising and addition of ferro-manganese	Ingot No. 1	0·11	0·46	...	...	...
	Ingot No. 2	0·11	0·48	...	0·047	...
	Ingot No. 3	0·12	0·48	...	...	...
	Ingot No. 4	0·11	0·47	0·034	0·048	0·008
	Ingot No. 5	0·12	0·47	...	...	...
	Ingot No. 6	0·11	0·46	...	0·047	...
	Ingot No. 7	0·11	0·47	...	...	...
	Ingot No. 8	0·11	0·47	...	0·046	...

Analysis of Slag Samples.

	Before Mixing.	After Mixing.
SiO_2. %	5·90	18·62
FeO. %	10·97	19·99
Fe_2O_3. %	22·96	4·10
MnO. %	0·88	3·37
CaO. %	50·15	41·85
MgO. %	5·18	4·10
P_2O_5. %	0·94	4·68

Notes on the Experiment.

(1) The result of this experiment was very satisfactory. A very good yield of manganese was obtained, which element was evenly distributed throughout the cast. The total loss of manganese was only 33%.

(2) Less slag was used in this experiment than in any previously conducted—the amount being about $7\frac{1}{4}$%—with the object of keeping the phosphorus in the finished steel above 0·04% and below 0·08%, which was successfully accomplished.

(3) The ingots were rolled into sheet bar. The rolling was very good, and the bars had an excellent appearance. They were subsequently rolled into sheets in the sheet mill with satisfactory results.

Heat No. P38.   23rd November, 1936.

The object of this experiment was to repeat heat No. *P*36 for the purpose of comparing the results of the two experiments.

Preparation of the Dephosphorising Slag.

In this experiment the same slag mixture was used as in heat No. *P*36.

Details of the Experiment.

Weight of iron blown . .	47 tons.
Bessemer blow numbers . .	$\begin{cases} 70,633 \\ 70,634 \end{cases}$
Duration of blows . .	$\begin{cases} 2.08\text{--}2.23 \text{ P.M. (15 min.)} \\ 2.19\text{--}2.37 \text{ P.M. (18 min.).} \end{cases}$
Weight of slag poured into casting ladle	3 tons.
Time slag poured into casting ladle	2.49–2.51 P.M.
Time blown metal poured down trough into casting ladle .	2.57–3.04 P.M.
Reaction in casting ladle .	Moderate, owing to slow pouring of metal. The reaction continued for 4 min.
700 lb. of ferro-manganese (Mn 75%) added red-hot in casting ladle as soon as dephosphorising reaction ceased . .	3.08 P.M.
Started casting ingots . .	3.13 P.M.
Finished casting ingots . .	3.30 P.M.
Dia. of nozzle . . .	$1\frac{3}{4}$ in.
Ladle	Similar to heat No. *P*36.
Weight of ingots cast . .	42 tons 4 cwt.
	8 ingots were cast in narrow-end-up moulds, and were allowed to rim. 2 oz. of aluminium were added in each mould. All the ingots rimmed in level and were capped.
Ladle skull	10 cwt.

Analysis of Metal Samples.

		O. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron	. . .	...	0·43	0·023	0·320	1·69
Blown metal from { 1st blow	.	0·08	...	...	...	...
each converter { 2nd blow	.	0·13	...	...	...	...
Blown metal before } Double		0·07	0·05	0·024	0·278	0·038
dephosphorising } blow						
	Ingot No. 1	0·11	0·37	...	...	...
	Ingot No. 2	0·12	0·38	...	0·052	...
Pitside ladle samples	Ingot No. 3	0·11	0·38	...	...	...
after dephosphoris-	Ingot No. 4	0·11	0·37	0·025	0·050	0·008
ing and addition of	Ingot No. 5	0·11	0·37	...	...	...
ferro-manganese	Ingot No. 6	0·11	0·37	...	0·051	...
	Ingot No. 7	0·12	0·39	...	...	...
	Ingot No. 8	0·11	0·38	...	0·053	...

Analysis of Slag Samples.

					Before Mixing.	After Mixing.
SiO_2.	%	.	.	.	6·21	11·76
FeO.	%	.	.	.	8·10	20·76
Fe_2O_3.	%	.	.	.	24·43	7·30
MnO.	%	.	.	.	1·03	2·90
CaO.	%	.	.	.	50·60	45·80
MgO.	%	.	.	.	5·34	4·61
P_2O_5.	%	.	.	.	0·98	3·62

Notes on the Experiment.

(1) The result of this experiment confirmed that of heat No. P36. Again a very good yield of manganese was obtained and this element was found to be uniformly distributed throughout the cast. The total loss of manganese in this experiment was about 36%.

(2) The quantity of slag used was about 7%, and the percentage of phosphorus in the finished steel compared closely with heat No. P36.

(3) The ingots were rolled into sheet bar, which had an excellent appearance. The bars were subsequently rolled into sheets in the sheet mill, with satisfactory results.

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After the very good results obtained with heats Nos. P36 and P38 and similar experiments, it was decided to adopt this method of adding manganese to the steel as standard procedure for future experiments.

In order to observe the effect of the quantity of synthetic slag used on the extent of the dephosphorisation, several experiments were conducted with smaller quantities of slag than were used in heats Nos. P36 and P38. Details of two such experiments are given as examples.

Heat No. P43.   25th November, 1936.

The object of this experiment was to dephosphorise, to a limited extent, two blows from the Bessemer converters by regulating the

quantity of slag used, and to add manganese to the dephosphorised metal in order to cast steel ingots suitable for rolling into tinbar, the chemical specification of which was as follows :

C. %.	Mn. %.	P. %.	S. %.
0·10–0·14	0·30–0·50	0·08–0·12	0·050 max.

Preparation of the Dephosphorising Slag.

In this experiment the same slag mixture was used as in heats Nos. *P*36 and *P*38.

Details of the Experiment.

Weight of iron blown . .	48 tons.
Bessemer blow numbers . .	$\begin{cases} 70{,}761 \\ 70{,}762 \end{cases}$
Duration of blows . . .	$\begin{cases} 10.09\text{–}10.27 \text{ A.M. (18 min.).} \\ 10.31\text{–}10.45 \text{ A.M. (14 min.).} \end{cases}$
Weight of slag poured into cast-ing ladle	2½ tons.
Time slag poured into casting ladle	10.50–10.52 A.M.
Time blown metal poured down trough into casting ladle .	10.55–11.00 A.M.
Reaction in casting ladle .	Very violent, persisted for 5 min.
700 lb. of ferro-manganese (Mn 75%) added red-hot in cast-ing ladle as soon as dephos-phorising reaction ceased .	11.05 A.M.
Started casting ingots . .	11.10 A.M.
Finished casting ingots . .	11.30 A.M.
Dia. of nozzle . . .	1¾ in.
Ladle	Similar to heats Nos. *P*36 and *P*38.
Weight of ingots cast . .	43 tons 9 cwt.
	9 ingots were cast in narrow-end-up moulds, and were allowed to rim. 2 oz. of aluminium were added to the first 3 ingots, which rose a little in the moulds before rimming in. 1 oz. of aluminium was added to the remaining 6 ingots, which rimmed in level with the pouring height. All the 9 ingots were capped.
Ladle skull	5 cwt.

Analysis of Metal Samples.

	C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron . . .	...	0·33	0·018	0·404	1·59
Blown metal from \ 1st blow .	0·15	...	...	...	...
each converter / 2nd blow .	0·24	...	...	...	...
Blown metal before \ Double dephosphorising / blow	0·19	0·13	0·021	0·328	0·084
Pitside ladle samples after dephosphoris- Ingot No. 2	0·11	0·42	...	0·128	...
ing and addition of Ingot No. 4	0·12	0·43	0·029	0·125	0·010
ferro-manganese Ingot No. 6	0·12	0·42	...	0·130	...

Analysis of Slag Samples.

						Before Mixing.	After Mixing.
SiO_2.	%	.	.	.	.	7·24	16·48
FeO.	%	.	.	.	.	6·19	26·96
Fe_2O_3.	%	.	.	.	.	27·71	5·86
MnO.	%	.	.	.	.	1·34	3·44
CaO.	%	.	.	.	.	47·80	37·30
MgO.	%	.	.	.	.	4·32	3·20
P_2O_5.	%	.	.	.	.	1·85	3·98

Notes on the Experiment.

(1) In this experiment the quantity of slag used was only $5\frac{3}{4}$%, which was evidently too little, for the percentage of phosphorus in the finished steel was on the high side of the specification. The result, however, showed the possibility of regulating, to some extent, the phosphorus content of the steel by employing different weights of slag.

(2) As in heats Nos. P36 and P38, there was a satisfactory yield of manganese, which was evenly distributed throughout the cast. The total loss of manganese in this experiment was the same as in heat No. P38, that is, 36%.

(3) The ingots were rolled into tinbar, which had an excellent appearance. The bars were subsequently rolled into tinplate with satisfactory results.

Heat No. P54. 10th December, 1936.

The object of this experiment was to repeat heat No. P43, but using a little larger percentage of synthetic slag, so as to produce ingots within the following chemical specification, suitable for rolling into tinbar :

C. %.	Mn. %.	P. %.	S. %.
0·10–0·14	0·30–0·50	0·08–0·12	0·050 max.

Preparation of the Dephosphorising Slag.

An entirely new slag was made for this and other experiments, by melting in a 250-ton open-hearth tilting furnace the following ingredients :

	Tons. Cwt.	SiO_2. %.	Fe_2O_3. %.	Al_2O_3. %.	CaO. %.	MgO. %.	Loss. %.
					Composition.		
Calcined lime	20 0	4·55	1·31	1·09	88·16	2·02	2·75
Mill scale	8 10						
		SiO_2. %.			CaF_2. %.		
Fluorspar	1 10	5·14			92·08		
Total	30 0						

The slag ingredients were charged on the top of about 30 tons of molten metal left in the furnace from the last heat tapped.

Details of the Experiment.

Weight of iron blown . .	43 tons.
Bessemer blow numbers . .	$\left\{\begin{array}{l}72,266 \\ 72,267\end{array}\right.$
Duration of blows . .	$\left\{\begin{array}{l}11.05\text{--}11.21 \text{ A.M. (16 min.)} \\ 11.09\text{--}11.26 \text{ A.M. (17 min.)}.\end{array}\right.$
Weight of slag poured into casting ladle	$2\frac{1}{2}$ tons.
Time slag poured into casting ladle	11.28 A.M.
Time blown metal poured down trough into casting ladle .	11.30–11.35 A.M.
Reaction in casting ladle .	Very violent, persisted for 5 min.
400 lb. of spiegel (Mn 27·5%) . 650 lb. of ferro-manganese (Mn 52·5%)	$\left.\begin{array}{l}\text{Added red-hot in casting ladle as soon as} \\ \quad \text{dephosphorising reaction ceased, 11.40} \\ \quad \text{A.M.}\end{array}\right.$
Started casting ingots . .	11.46 A.M.
Finished casting ingots . .	12.05 P.M.
Dia. of nozzle . . .	$1\frac{3}{4}$ in.
Ladle	Similar to heats Nos. P36, P38 and P43.
Weight of ingots cast . .	39 tons 2 cwt.
	8 ingots were cast in narrow-end-up moulds, and were allowed to rim. 2 oz. of aluminium were added to the first 2 ingots, which rose a little in the moulds, and 1 oz. to the remaining 6 ingots, which rimmed in level. All the 8 ingots were capped.
Ladle skull	5 cwt.

Analysis of Metal Samples.

		C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron . . .		...	0·49	0·022	0·312	1·57
Blown metal from each converter	1st blow ,	0·19	...	...	...	...
	2nd blow .	0·19	...	...	...	...
Blown metal before dephosphorising	Double blow	0·19	0·15	0·024	0·288	0·103
Pitside ladle samples after dephosphoris- ing and addition of spiegel and ferro- manganese	Ingot No. 2	0·11	0·42	...	0·082	...
	Ingot No. 4	0·12	0·42	0·025	0·080	0·010
	Ingot No. 6	0·11	0·42	...	0·083	...

Analysis of Slag Samples.

	Before Mixing.	After Mixing.
SiO_2. %	4·34	15·57
FeO. %	7·98	16·96
Fe_2O_3. %	20·78	4·44
MnO. %	0·41	2·80
CaO. %	59·20	49·81
MgO. %	3·11	2·82
P_2O_5. %	0·23	2·95

Notes on the Experiment.

(1) The amount of slag used in this experiment was a little over $6\frac{1}{4}\%$, and the percentage of phosphorus in the resultant steel finished within the chemical specification. The amount of phos-

phorus in the blown metal was, however, 0.04% less than in heat No. P43.

(2) The yield of manganese was satisfactory, and this element was uniformly distributed throughout the cast. The total loss of manganese was 35%.

(3) The ingots were rolled into tinbar which had an excellent appearance. The bars were subsequently rolled into tinplate with satisfactory results.

EXPERIMENTS ON THE DEPHOSPHORISATION OF STEEL WITH BASIC OPEN-HEARTH FURNACE SLAG AT THE TATA IRON AND STEEL WORKS, INDIA.

A review of the information gained from the results of experiments on the dephosphorisation of steel by means of the Perrin *synthetic slag* suggested to the author the possibility of employing molten *basic open-hearth furnace slag* for dephosphorising purposes, particularly slag with a high iron oxide content taken from the tilting furnace directly after tapping low-carbon rimming steel heats made by the duplex process. Therefore a series of experiments was conducted with basic open-hearth furnace slag, and the chief particulars of three such experiments are given as typical examples of the results obtained.

Heat No. P69. 11*th September*, 1937.

The object of this experiment was to dephosphorise two blows from the Bessemer converters by using open-hearth basic slag instead of synthetic slag, and then to add both manganese and silicon to the dephosphorised blown metal in order to cast " semi-killed " ingots of dead soft quality, to the following chemical specification :

C. %.	Mn. %.	P and S. %.
0·12 max.	0·30–0·45	0·050 max.

Preparation of the Dephosphorising Slag.

The slag used was taken from one of the duplex basic open-hearth tilting furnaces directly after tapping a dead-soft rimming steel heat of composition similar to that being attempted in this experiment.

Details of the Experiment.

Weight of iron blown . .	39 tons 8 cwt.
Weight of slag poured into casting ladle	4½ tons.
Reaction in casting ladle .	Moderate.
Additions to dephosphorised blown metal	650 lb. of lump ferro-manganese (Mn 75%) and 400 lb. of lump ferro-silicon (Si 22%), added together red-hot in the casting ladle through the slag after dephosphorising, immediately the reaction ceased.

Dia. of nozzle . . .	2 in.
Ladle lining (100-ton ladle) .	Firebrick; fireclay stopper coated with chromite paste.
Weight of ingots cast . .	35 tons 10 cwt.
	7 ingots were cast in narrow-end-up moulds. 3 lb. of aluminium were added to the first ingot, which rose in the mould and had a spongy top. The remaining 6 ingots, to each of which 5 lb. of aluminium were added, had very slightly rising tops.
Weight of aluminium used .	33 lb.
Ladle skull	10 cwt.

Analysis of Metal Samples.

		C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron . . .		...	0·39	0·037	0·328	1·49
Blown metal from \ 1st blow .		0·10	...	...	...	...
each converter ∫ 2nd blow .		0·06	...	...	...	...
Blown metal before \ Double dephosphorising ∫ blow		0·08	0·06	0·039	0·295	0·016
Pitside ladle samples ⎫						
after dephosphoris- ⎪	Ingot No. 2	0·09	0·40	...	0·053	0·035
ing and additions ⎬	Ingot No. 4	0·09	0·39	0·040	0·053	0·035
of ferro-silicon and ⎪	Ingot No. 6	0·09	0·40	...	0·055	0·033
ferro-manganese ⎭						

Analysis of Slag Samples.

					Before Mixing.	After Mixing.
SiO_2.	% .	.	.	.	12·10	18·20
Al_2O_3.	% .	.	.	.	2·16	3·48
FeO.	% .	.	.	.	20·70	17·68
Fe_2O_3.	% .	.	.	.	8·00	3·94
MnO.	% .	.	.	.	3·90	5·86
CaO.	% .	.	.	.	44·35	39·65
MgO.	% .	.	.	.	4·10	4·03
P_2O_5.	% .	.	.	.	4·48	6·59

Notes on the Experiment.

(1) Hitherto, only the manufacture of rimming steel had been attempted, but this experiment was conducted with the object of introducing silicon into the dephosphorised blown metal in addition to manganese, so as to produce ingots of the semi-killed type. To effect this purpose, low-grade ferro-silicon (silicon 22%) was chosen because its specific gravity was higher than that of the slag. Both the ferro-silicon and the ferro-manganese were roasted, and added together in a red-hot condition through the dephosphorising slag in the casting ladle. It was found that about 1 lb. of aluminium per ton of steel was required to control the ingot tops and prevent the steel from rising too much in the moulds.

(2) The manganese and silicon were evenly distributed throughout the cast, but there was a total loss of 72% of silicon and 43% of manganese.

(3) It is noteworthy that, whereas the major portion of the iron oxide in the synthetic slag occurred in the form of Fe_2O_3,

in the basic open-hearth slag most of the iron oxide was in the form of FeO. Thus they could easily be distinguished.

(4) The quantity of open-hearth slag used was $12\frac{1}{2}\%$, notwithstanding which the dephosphorisation was insufficient and the phosphorus in the steel finished on the high side of the chemical specification aimed at.

(5) Thus it is seen that the dephosphorisation with the basic open-hearth slag was not so intensive as with the Perrin synthetic slag. This, of course, was due to the higher acidity of the furnace slag.

(6) The ingots were rolled successfully into 8-in. square blooms and then into 2-in. square billets for the merchant mill, where they were finally rolled into $\frac{9}{16}$-in. dia. rounds.

Heat No. P85. 18th September, 1937.

The object of this experiment was to dephosphorise two blows from the Bessemer converters by using open-hearth basic slag instead of synthetic slag; then to add manganese to the dephosphorised blown metal in the casting ladle, and silicon in the moulds, in order to produce semi-killed ingots, suitable for rolling into sheet bar, to the following chemical specification :

C. %.	Mn. %.	S. %.	P. %.
0·11–0·15	0·30–0·50	0·050 max.	0·05–0·09

Preparation of the Dephosphorising Slag.

The slag used was taken from one of the duplex basic openhearth tilting furnaces, directly after tapping a rimming steel heat for sheet bar of composition similar to that being attempted in this experiment.

Details of the Experiment.

Weight of iron blown	40 tons 10 cwt.
Weight of slag poured into casting ladle	4 tons.
Reaction in casting ladle	Moderate.
Additions to dephosphorised blown metal	1150 lb. of lump ferro-manganese (Mn 47·5%) added red-hot in casting ladle through slag after dephosphorisation. 8 lb. of crushed ferro-silicon (Si 75%) added to each ingot during teeming.
Dia. of nozzle	2 in.
Ladle lining (100-ton ladle)	Firebrick; fireclay stopper coated with chromite cement.
Weight of ingots cast	36 tons $14\frac{1}{2}$ cwt. 7 ingots were cast in narrow-end-up moulds; 4 lb. of aluminium were added to the first ingot, which piped badly; 3 lb. were added to the second and third ingots, which piped slightly; to each of the remaining 4 ingots, which had flat tops, $2\frac{1}{2}$ lb. of aluminium were added.
Weight of aluminium used	20 lb.
Ladle skull	8 cwt.

Analysis of Metal Samples.

		C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron . . .		...	0·51	0·036	0·320	1·56
Blown metal from \ 1st blow .		0·09	...	...	...	...
each converter ∫ 2nd blow .		0·09	...	...	...	...
Blown metal before \ Double		0·09	0·04	0·039	0·288	0·017
dephosphorising ∫ blow						
Pitside ladle samples \	Ingot No. 2	0·10	0·47	...	0·067	0·042 *
after dephosphoris- \	Ingot No. 4	0·11	0·48	0·039	0·068	0·040 *
ing and addition of \	Ingot No. 6	0·12	0·49	...	0·065	0·043 *
ferro-manganese ∫						

* Ferro-silicon added in moulds; therefore drillings taken from ingots.

Analysis of Slag Samples.

					Before Mixing.	After Mixing.
SiO_2.	% .	.	.	.	12·00	19·80
Al_2O_3.	% .	.	.	.	2·08	4·42
FeO.	% .	.	.	.	19·20	16·78
Fe_2O_3.	% .	.	.	.	8·00	2·86
MnO.	% .	.	.	.	4·54	6·78
CaO.	% .	.	.	.	44·05	38·00
MgO.	% .	.	.	.	4·80	3·60
P_2O_5.	% .	.	.	.	4·44	6·83

Notes on the Experiment.

(1) This experiment differed from heat No. *P*69 in that the manganese was separated from the silicon, by adding the former red-hot in lump form through the slag in the casting ladle, and the latter in crushed form in the moulds. In this experiment, only half the quantity of aluminium (8 oz. per ton of steel) was required, compared with the amount used in heat No. *P*69.

(2) The quantity of furnace slag used in this experiment was about $10\frac{3}{4}\%$, compared with $12\frac{1}{2}\%$ in heat No. *P*69, and the extent of dephosphorisation was correspondingly less in this than in the former experiment.

(3) The manganese efficiency in this experiment was very high, the total loss of this element being only 30%.

(4) The ingots were successfully rolled into sheet bar and subsequently, with satisfactory results, into sheets in the sheet mill.

Heat No. P100.   10*th November*, 1937.

The object of this experiment was to dephosphorise two blows from the Bessemer converters by using open-hearth basic slag; then to add manganese to the dephosphorised blown metal in the casting ladle, but no silicon at all, in order to produce rimming steel ingots suitable for rolling into merchant mill billets, to the following chemical specification :

C. %.	Mn. %.	P and S. %.
0·10–0·14	0·30–0·50	0·050 max.

Preparation of the Dephosphorising Slag.

The slag used was taken from one of the duplex basic open-hearth tilting furnaces, directly after tapping a rimming steel heat of composition similar to that being attempted in this experiment.

Details of the Experiment.

Weight of iron blown . .	40 tons 5 cwt.
Weight of slag poured into casting ladle	$5\frac{1}{2}$ tons.
Reaction in casting ladle .	Violent, lasting for 5 min.
Addition to dephosphorised metal	1150 lb. of lump ferro-manganese (Mn 47·5%) added red-hot in casting ladle through slag after dephosphorisation.
Dia. of nozzle . . .	2 in.
Ladle lining (100-ton ladle) .	Firebrick; fireclay stopper coated with chromite cement.
Weight of ingots cast . .	36 tons 8 cwt.
	7 ingots were cast in narrow-end-up moulds, and were allowed to rim. 2 oz. of aluminium were added to the first 2 ingots, which sank in the moulds. 4 oz. of aluminium were added to the remaining 5 ingots, which rimmed in level.
Ladle skull	5 cwt.

Analysis of Metal Samples.

	C. %.	Mn. %.	S. %.	P. %.	Si. %.
Blast-furnace iron . . .	...	0·97	0·020	0·364	1·79
Blown metal from 1st blow .	0·16	...	...	...	...
each converter 2nd blow .	0·15	...	...	...	...
Blown metal before Double dephosphorising blow .	0·15	0·20	0·021	0·305	0·104
Pitside ladle samples after dephosphorising and addition of ferro-manganese — Ingot No. 2	0·14	0·47	...	0·041	...
Ingot No. 4	0·13	0·46	0·022	0·040	0·010
Ingot No. 6	0·14	0·46	...	0·039	...

Analysis of Slag Samples.

	Before Mixing.	After Mixing.
SiO_2. %	11·40	19·80
Al_2O_3. %	2·44	3·38
FeO. %	20·64	16·25
Fe_2O_3. %	7·30	2·40
MnO. %	4·36	6·45
CaO. %	45·50	40·15
MgO. %	3·46	3·24
P_2O_5. %	4·35	7·10

Notes on the Experiment.

(1) This experiment differed from heats Nos. P69 and P85 in that manganese only was added to the dephosphorised blown metal, so as to produce rimming steel ingots and not ingots of the semi-killed type as in the two previous experiments under reference.

Thus a comparison was made with the rimming steel ingots pro-
duced in the earlier experiments described in which a synthetic
slag was used.

(2) A larger percentage of furnace slag was used in this ex-
periment than in heats Nos. P69 and P85, with the object of
keeping the phosphorus below 0·05% in the finished steel. This
was accomplished, but as much as 15% of furnace slag was em-
ployed.

(3) The total loss of manganese in this experiment was about
40%.

(4) The ingots were successfully rolled into 8-in. square blooms
and then into 2-in. square billets for the merchant mill, where
they were finally rolled into $\frac{9}{16}$-in. dia. rounds with satisfactory
results.

It will be observed from the results obtained that the dephos-
phorisation accomplished with basic open-hearth furnace slag was
not so intensive as with the Perrin synthetic slag, so that much
more of the former slag had to be employed to obtain the same
degree of dephosphorisation, owing to the comparatively higher
acid content ($SiO_2 + P_2O_5$) of the furnace slag. Nevertheless, it
is obvious that 50% of suitable furnace slag (as low in acids as
possible) reconditioned with 50% of raw materials in the propor-
tions used for making the Perrin synthetic slag, could be efficiently
employed for dephosphorising purposes, thus reducing by half the
cost of the fluxes.   Fig. 1 illustrates the comparative dephosphoris-
ing properties of Perrin synthetic slag and basic open-hearth
furnace slag.

The results of the experiments also showed that, although killed
and semi-killed low-carbon steel could be made if required at the
expense of a lot of aluminium or other deoxidiser, the slag-dephos-
phorising direct process was much better and more economically
suited for the production of low-carbon rimming steel.

Altogether, in the 100 experimental heats made over a period
of two years, more than 3000 tons of ingots were produced by the
slag-dephosphorising direct process, with an average yield of 90·35%
of ingots from blast-furnace iron plus alloy additions ; and as the
ingots were rolled into various products mostly with satisfactory
mill yields, it was considered that the experimental stage had been
passed and sufficient information obtained to ensure that the
Perrin process could be operated successfully on a commercial
scale in a new plant specially designed for the process.   It should
also be mentioned that several ingots were sliced horizontally and
longitudinally for a thorough metallurgical examination and for com-
parison with similar types of ingots made by the basic open-hearth
and duplex processes, and it was found that the ingots made by
the slag dephosphorisation process were in no way inferior to
ingots made by the other processes.

In fact, the results of the experiments were considered to be so satisfactory that the Tata Iron and Steel Company purchased the patent rights for the Perrin process for India and Burma, and are erecting a new plant to operate the process on a site adjacent to the existing duplex plant at Jamshedpur.

As only soft steels up to about 0·15% of carbon can be made direct from the Bessemer converter by the Perrin process, it will be necessary when producing higher-carbon and alloy steels to charge the dephosphorised blown metal into a melting furnace (either acid or basic lined) for the addition of the necessary carbon and alloys.[1]
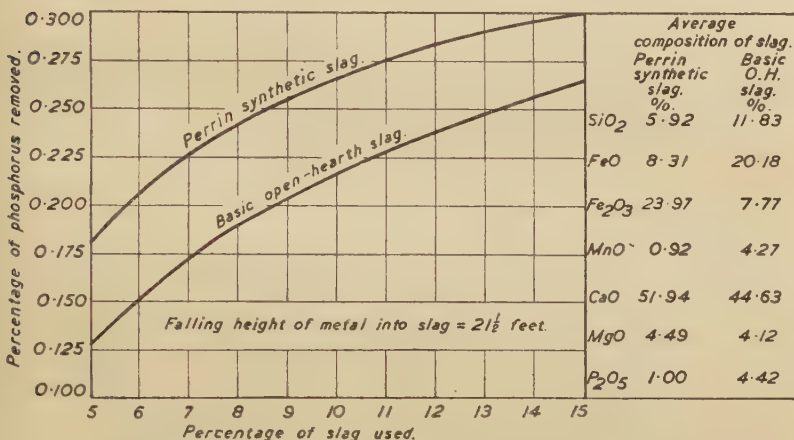
FIG. 1.—Effect of Varying Percentages of Slag on the Removal of Phosphorus from Steel by the Slag Dephosphorising Process.

PERRIN PROCESS PLANT; METHOD OF OPERATION.

Blast-furnace iron of suitable composition (1·10–1·30% of silicon and 0·30–0·60% of manganese) will be delivered in 60-ton ladles to the Perrin process plant and poured into the hot-metal mixer by means of a 100-ton ladle crane. Twenty-four tons of mixer iron will be poured from the hot-metal mixer into a 30-ton ladle supported on an electrically-driven ladle car by which it will be conveyed to one of the 25-ton Bessemer converters. The

[1] For the production of higher-carbon and certain alloy steels, Mr. Perrin has conceived the idea of pouring the dephosphorised blown metal back into the same or into another hot acid converter, the basic slag being thus separated from the treated metal. Silicon and/or manganese are next added to the dephosphorised metal, which is then blown for a few seconds to oxidise the elements added and so to increase the heat of the metal to ensure a sufficiently high casting temperature. After turning down the converter, the required final alloy and carbon additions are made either in the converter or in the casting ladle, according to the chemical specification of the steel required.

iron will then be poured into the converter by means of an electrically-operated tilting device.

For the production of low-carbon steel ingots direct from the converter, the iron will be blown until the carbon is about $0·10\%$. The required weight of dephosphorising slag will be poured from the slag mixer into a casting ladle of 50 tons capacity [1] supported on a truck, just prior to the converter being turned down. An electric lorry will then place the ladle under the converter, and the blown metal will be poured slowly into the dephosphorising slag from a height of more than 20 ft. Immediately the dephosphorising reaction has subsided, the ladle of slag and metal will be transferred under the chute of one of the ferro-manganese roasting furnaces, and the red-hot lump alloy will be ejected therefrom and will fall down the chute into the casting ladle. The latter will then be conveyed to a position from where it can be hoisted by one of the 100-ton ladle cranes and carried to the casting platform. Five minutes after the addition of the ferro-manganese, the steel will be cast into ingots. Four moulds on stools will be set on one ingot bogie, and, taking the yield at 90%, four ingots each weighing 108 cwt. will be cast.

For the production of higher-carbon and alloy steels, the Bessemer blow will be stopped at a higher carbon content than that required by the chemical specification of the steel. The dephosphorised blown metal containing carbon will be hoisted by one of the 100-ton ladle cranes and poured down a chute into one of the finishing furnaces. Four dephosphorised blows will be required to fill each of the 80-ton open-hearth furnaces, from which the equivalent weight of about two blows will normally be tapped as finished steel into a 50-ton casting ladle, leaving in the furnace approximately half the quantity of metal charged, to which two dephosphorised blows will be added and the process repeated. Ingots of various weights will be cast from acid open-hearth steel in accordance with the requirements of the wheel, tyre and axle plant which is being erected at the same time as the Perrin process plant.

As it will therefore be necessary at times to dephosphorise blown metal containing considerable percentages of carbon, experiments were carried out to ascertain how far this was possible. Particulars of one such experiment are given below as an example.

Heat No. P5.   12th November, 1935.

The object of this experiment was to dephosphorise mixer iron blown in the Bessemer converter for a few minutes in order to remove almost all of the silicon (and manganese) while retaining a high percentage of carbon in the iron.

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[1] The capacity of the casting ladle is double that necessary for the steel, because of the space required to allow for the rising of the slag in the ladle during the violent dephosphorising reaction.

Preparation of the Dephosphorising Slag.

The same slag mixture was used in this experiment as in heat No. *P*3.

Details of the Experiment.

Weight of iron blown   .   .   23 tons.
Duration of blow   .   .   .   5 min.
Weight of slag poured into cast-
    ing ladle   .   .   .   .   3 tons 5 cwt.
Reaction in casting ladle   .   Very violent with much flame owing to
                                the oxidation of a considerable quan-
                                tity of carbon. After mixing, the
                                dephosphorised iron was re-ladled
                                from the casting ladle into a converter
                                ladle and conveyed to the Bessemer
                                shop for further blowing, after which
                                the blown metal was transferred to
                                one of the duplex furnaces.
Ladle lining (100-ton lable)   .   Ordinary firebrick, not fitted with
                                stopper.

Analysis of Metal Samples.

	C. %.	Mn. %.	S. %.	P. %.	Si. %.
Mixer iron	3·95	0·54	0·022	0·280	0·920
Blown metal before dephosphoris-ing	3·25	0·20	0·023	0·295	0·035
Blown metal after dephosphoris-ing	2·64	0·08	0·024	0·035	0·006

Analysis of Slag Samples.

	Before Mixing.	After Mixing.
SiO_2. %	8·23	13·60
Al_2O_3. %	1·67	2·09
FeO. %	7·81	14·00
Fe_2O_3. %	22·83	8·48
MnO. %	7·05	8·80
CaO. %	47·20	43·90
MgO. %	3·74	3·02
P_2O_5. %	0·51	4·54
TiO_2. %	Nil	0·53
S. %	Trace	0·10

Notes on the Experiment.

(1) The result of this experiment showed that the dephos-phorisation of iron even in the presence of a high percentage of carbon could be successfully accomplished, provided that there was not too much silicon present in the iron. Thus it is seen how flexible is the slag dephosphorising process.

(2) Taking the yield of blown metal at about 95%, the quantity of synthetic slag used for dephosphorisation was nearly 15%.

In summing up the possibilities of the Perrin process as applic-able to the conditions at Jamshedpur, any possible value of the used dephosphorising slag as an artificial fertiliser has been ruled

out of consideration, owing to its contamination with acid Bessemer slag, and the necessity to use fluorspar to obtain the essential fluidity of the slag.   Moreover, it is evident that on account of the loss of phosphorus by volatilisation during blowing, there is an insufficient percentage of this element in the blown metal to yield a sufficiently high P_2O_5 content of the slag, even when the following precautions are taken :

(a) The use of a minimum percentage of slag for dephosphorisation ;

(b) the prevention, as much as possible, of the acid Bessemer slag from entering the casting ladle ;

(c) the lining of the casting ladle with basic refractories, the extra expenditure on which would, of course, offset to a considerable extent the possible sale value of the used slag.

DISCUSSION.

In the absence of the AUTHOR, this paper was presented by Dr. T. SWINDEN (Member of Council, Stocksbridge).

Dr. T. SWINDEN (Member of Council, Stocksbridge), opening the discussion, said that those who had had the privilege of meeting Mr. Perrin and seeing something of his work at Ugine had, he was sure, been impressed by this practical application of the principles which he had done so much to further. Those principles consisted, briefly, of speeding up the normal metallurgical reactions by facilitating intimate contact between metal and slag. The slag must, of course, be of adequate composition for the particular type of reaction involved, and it followed that it should be sufficiently fluid and at a sufficiently high temperature. The Perrin principle consisted essentially of pouring the metal into the slag from a specified suitable height. The author preferred to use a greater height of fall than had been suggested in the first place by Mr. Perrin, namely, about 20 ft. as against about 12 ft .

He was sure that everyone would recognise in the paper a most painstaking piece of work, carried out with meticulous care and reported in a particularly clear manner, and one was impressed by the persistence with which the work had been continued. The author and his colleagues had not been discouraged by the comparatively unsatisfactory results obtained at Ugine and had proceeded to work out a precise process suited to the treatment of Indian iron of the analysis stated, until the experiments were so satisfactory as to persuade the Tata Iron and Steel Company to plan and construct an entirely new steelworks adapted to the carrying out of the process. He had had the benefit of some talk with Mr. Richard Mather, the Technical Director of the Company, and it was quite evident that the scheme had been very carefully planned and was calculated to produce steel which was quite satisfactory for the purposes in view. Furthermore, it would be recognised that it provided a means of producing, by duplexing the slag-treated metal in an acid open-hearth furnace, a steel of open-hearth type, thus enabling the Company to avoid the importation of iron suitable for the direct acid open-hearth process, of which none was available in India.

The Members owed a deep debt of gratitude to the author and to all those responsible for the work in question, for having described it in such a detailed way, thus enabling others to consider the possibilities of the slag treatment for dephosphorising on a more satisfactory basis than had hitherto been possible. It represented, to the best of his knowledge, the first large-scale application outside France of the slag-treatment process initiated by Mr. Perrin.

The extent to which advantage could be taken in Britain of the work in question, particularly in the present circumstances, required very careful consideration. Certain essential conditions required to be complied with. It would seem necessary that there should be available a ready and regular supply of molten steel, and that would seem to be most readily provided by a group of Bessemer converters. Special plant was required by way of slag-melting furnaces, and, accepting the work presented by the author, also special furnaces for the preheating of the ferro-manganese. Further, if steel other than rimming steel or dead-soft steel was to be produced, it was essential that open-hearth furnaces, either basic or acid, should be operated adjacent to the slag-treating plant, for increasing the carbon or adding alloys.

Such were the conditions which required to be visualised in applying the scheme on a really large-scale commercial basis. Experiments were in fact being carried out by which it was possible that at least a partial application of the slag-treatment idea might be utilised for irons which would not otherwise be suitable, for example, for acid steelmaking, and the possibilities of its utilisation in the treatment of special iron for the foundry industry had not been overlooked.

He would conclude by commending the paper as a description of an excellent piece of work, recorded in such detail as to enable anyone interested in the subject to study it carefully and consider what advantage, if any, could be derived in his own circumstances from the work which had been carried out.

Mr. J. H. WHITELEY (Consett, Co. Durham), said that he re-garded this paper as one of the most interesting on steelmaking that the Institute had received for many years. Both from the practical and the theoretical standpoints it contained much that required careful consideration. One of the outstanding facts was the rapidity with which the reactions occurred. Mr. Perrin had found that in less than one minute the silicon content of a purposely over-oxidised steel could be raised from a trace to 0.2%, and here Mr. Yaneske demonstrated that in an equally short time 0.2% of phosphorus could be removed. No doubt the fairly intimate mixture of slag and metal in the ladle brought this about, yet, considering the relatively tardy rates of these reactions in the open-hearth furnace, such marked activity would scarcely have been expected. Another striking fact revealed by the data in the paper was the much greater oxidising power of Fe_2O_3 as compared with FeO. That was particularly clear in the heats where a synthetic slag was used, for in nearly every instance there was a large increase in the FeO content of the slag after dephosphorisation and a cor-respondingly large reduction of the Fe_2O_3. Thus the 50% extra oxygen in the Fe_2O_3 had done most of the work, a fact which tended to support a conclusion that he (Mr. Whiteley) and Dr. Hallimond

had reached many years ago [1] in studying acid open-hearth slags, which was that the carbon elimination was chiefly due to the very small amount of Fe_2O_3 constantly maintained in the slag by gas oxidation and ore additions. Their view was that most of the FeO in a normal slag was held in combination with the SiO_2 and the little that was dissociated was much less active in removing carbon than the Fe_2O_3; indeed, they believed the latter was not for the most part reduced to iron but to FeO, which was again oxidised by the gases and so acted as an oxygen carrier. The extent to which FeO was reduced would probably depend upon the slag composition; in a highly ferruginous slag of comparatively low acidity a greater direct elimination of FeO would be expected, as had happened in the three heats where a duplex slag had been used. In these instances, however, the lowering of the FeO contents was almost certainly due to an insufficiency of Fe_2O_3, but, in any case, it was evident that either oxide would serve in the Perrin process.

He thought that the last heat described in the paper was particularly interesting, since Mr. Yaneske had there shown that dephosphorisation could be carried out successfully even when the metal contained more than 3% of carbon. In this connection he (Mr. Whiteley) would like to ask the author whether he had tried to dephosphorise metal straight from the blast-furnace by using, say, 4 tons of a synthetic iron low in silica. It seemed possible that the heat liberated by the oxidation of the silicon and phosphorus would raise the temperature sufficiently to enable the metal to be subsequently blown in the converter.

There was one other question that he wished to ask. Mr. Yaneske had used basic iron comparatively low in phosphorus. Would the Perrin process be equally efficient in dephosphorising metal containing, say, 1·5% of phosphorus if a much greater volume of slag was used?

Mr. R. PERCIVAL SMITH (Sheffield) said that it seemed particularly appropriate that Dr. Swinden should have introduced the paper, because he had been one of the first to take an interest in the work done by Mr. Perrin at Ugine.

The paper was, to his mind, an object-lesson to the Members. In it the author described one hundred casts made at the Tata Company's works, that was to say, he was actually describing a gigantic experiment, in which 3,000 tons of steel were produced, undertaken by a private company. It was quite obvious that the author and his associates had not attempted to answer and could not answer in such a paper the questions that must spring to the mind of every steelmaker, but at any rate the Tata Company had made a wonderful effort to solve for its own purposes a problem in steelmaking. Again and again in the paper the author referred

[1] *Journal of the Iron and Steel Institute*, 1919, No. I., p. 199.

to the steel produced as satisfactory. Naturally the steelmaker asked "Satisfactory for what purpose?" There were a hundred different purposes. The steel might be satisfactory for one purpose and quite unsatisfactory for another; it was a matter of great importance that that question and also others should be answered.

The paper seemed to be one of the utmost importance. If one private company could afford to do the work described therein, what could the steel trade acting as a whole do in the matter? Steel was not being made in a satisfactory way in the open-hearth furnace; all steelmakers knew in their inmost hearts that the open-hearth furnace was an extremely unsatisfactory tool with which to work. How could any steelmaker be proud of a tool that could not give him more than 20% efficiency and with which he had to labour for hours in order to get what he wanted? When one read the paper one began to wonder whether it would not be worth while for steelmakers to combine in trying to solve the problem dealt with therein. The technical skill and the scientific skill required were certainly available.

The suggestion contained in the final paragraph of Mr. Whiteley's remarks was another adaptation of the Perrin process. This adaptation would be intended to reduce the phosphorus content of the metal in cases where it was high and so convert an iron unsuitable for basic open-hearth practice into one well adapted for the purposes.

Mr. A. ROBINSON (Scunthorpe, Lincolnshire) said that one very important point in the process was the method of melting the slag. He would like to know whether a satisfactory furnace and a satisfactory lining for the bottom and banks of that furnace, capable of standing up against the slag, had been found, because people engaged in making steel knew very well that the material that did most damage to their bottoms, banks and linings was the slag itself.

He would also like to know the temperatures of the steel and slag before and after treatment, as there might be the possibility of heavy metal skulls being formed.

Mr. J. MITCHELL (Kettering) said that, speaking as one who had been in contact with Mr. Perrin, there were a few points to which he thought attention should be drawn. Those who had studied Mr. Perrin's ideas, not only the dephosphorising proposals dealt with in the paper but also his deoxidation method, must have been very much impressed by the lucidity of his technical and theoretical thinking. Where most people had become doubtful, he was afraid, was on the practical application of the ideas, owing to the difficulties involved.

So far as the paper was concerned, he thought it was a matter of extreme interest that the very careful way in which the work

had been documented had shown quite clearly that Mr. Perrin's theoretical considerations were perfectly correct. He himself would be very proud to find such excellent confirmation in large-scale laboratory experiments of what he set out to do.

The record of tests given in the paper would provide subject-matter for all those who delighted in the discussion of the effects of oxygen and the oxygen reactions, but, looking at the results given by the author, he thought it was perfectly clear that there were two things which could not be done satisfactorily in the steel-making operation. One could not start with a high-phosphorus iron, remove the phosphorus in a hurry and hope to have what might be called a first-grade steel. He knew there were makers of tin-bar present who would object to Mr. Percival Smith's quali-fication as to what was a satisfactory quality, but he thought it was abundantly clear—and it had been demonstrated once again in the paper—that there must be a certain order of removal of the undesired elements and there must be a certain rate of removal. Mr. Whiteley had expressed surprise that the reactions took place so quickly, but, after all, nearly 2% of phosphorus was taken out of the metal in a little less than two minutes in a Bessemer converter.

He thought the moral of the paper was that, given the necessary intermixing with a suitable slag, one could do almost anything that one wanted to do in practical work. Dr. Swinden had referred to pouring the metal into the slag from a suitable height. He would say from his experience (he had had a little experience in the way of trials in connection with the Perrin process, both in Britain and in France) that that was the essential practical detail, and with existing plants it would also be the main difficulty in the application of the process.

Mr. A. G. Hock (Workington) expressed his admiration of the author's work and said that it would be of interest to learn what effect the temperature of the slag had upon the results.

Mr. J. S. Gerber (Low Moor, near Bradford) said that in reading the paper it had struck him that the process described had some points in common with the Aston-Byers process and also with the washing process that had been used in America long before the Aston-Byers process was introduced.

Before he had heard about it, he had carried out some experi-ments which had a bearing on the Perrin process, and had found that, by adding a certain amount of molten " pure " pig iron of the right composition to the slag and then pouring the metal on to the slag, one obtained quite interesting results. The metal was practically killed, and high-carbon dephosphorised steels were thus produced.

He also wondered whether pouring the metal out of a lip-poured ladle from a height of 20 ft. could be avoided and the metal

be poured from a lower height from a bottom-poured ladle (thereby attaining the requisite pressure from a lower height and also obviating the necessity of removing the acid slag), and also whether that would materially affect the process, and possibly make it less difficult.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), said he was glad to say a few words on the paper, because Mr. Perrin had been so generous to steelmakers in Britain ; he had invited them to visit his works, and a number of Members of different firms had accepted the invitation. The whole process had been made an open book to them ; they had afterwards exchanged their experiences of what they had learned at Ugine and great note had been taken of a very interesting process.

Theoretically the Perrin process was most interesting, but, of course, everything turned on the application of such a process, and several matters came to his mind in that connection. He spoke from experience and with authority, because, like the Tata Works, the Firth-Brown Works had carried out a long run on the Perrin process and made a number of casts of steel, but its object had not been the same as that of the Tata Company. Its object had not been to dephosphorise but to test another claim of Mr. Perrin's, *i.e.*, that, by giving suitable compositions to the steel and slag and by rapidly intermixing the metal and the slag, one might produce a cleaner steel, getting rid of the inclusions. When experiments were carried out on a large scale it was necessary to improvise ; the Firth-Brown Works had improvised quite successfully, and Mr. Perrin and his colleagues had been satisfied that a very reasonable attempt had been made to try out the process in question. The steel made in this way had been quite good.

When one came to deal with the question of making clean steel, the steel was already in the furnace in quite an advanced condition with regard to the reactions, and one had to judge whether to let it remain in the furnace and continue the reactions there or to adopt Mr. Perrin's somewhat revolutionary method of taking the steel out of the furnace, mixing it with slag, and so on. The outcome of the experiments made by the Firth-Brown Works was not to condemn the Perrin process, but, on the other hand, not to adopt it. He did not wish that to be taken as a criticism of the Perrin process, because, if the Firth-Brown Works had determined that their steel should be made by the Perrin process and had continued experimenting for months instead of weeks, no doubt they would have improved their application of the process.

With regard to Mr. Percival Smith's suggestion that the industry as a whole should deal with the matter, he was sure that all the firms that had done work in that field would be very glad to exchange their experience. Experiences were being exchanged on everything to-day.

The Perrin process brought home to those who had taken an interest in the open-hearth process for a long time the fact that the reactions took place at the interface between the slag and the metal; it was simply the bottom of the slag reacting with the top of the metal all the time. If one could bring about a complete mixing of the two, one would expect a rapid action. As to how that was to be done, one must arrange for the production of the slag at the proper position and at the proper temperature at the moment when the steel was ready to be mixed with it. That was not as easy as it appeared to be, and that led him to enquire as to the cost of the Perrin process. As he had said, a regularised process was disturbed by the somewhat revolutionary procedure suggested, which could not be introduced except at a cost; he would like to know what that would be—for instance, for maintenance, and for running the slag furnace—so that one might see the influence on the economics of the process.

Another thought that came into his mind was that at any given moment in the open-hearth furnace the composition of the slag was that which resulted from its history, whereas in the Perrin process one created for the moment, and he rather thought that an appreciation of the facts emphasised by Mr. Perrin would lead to a general material improvement in open-hearth practice. In saying that, he intended to pay a compliment to Mr. Perrin.

Mr. D. MANTERFIELD (Sheffield) said that, in comparing the effectiveness of synthetic slag with basic open-hearth slag, the author suggested that the increased efficiency of the synthetic slag was due solely to the higher acid content of the basic open-hearth slag. He wondered whether it was not due also, perhaps to a greater extent, to the excess Fe_2O_3 in the synthetic slag as compared with the basic open-hearth slag. It was a curious fact, as Mr. Whiteley had said, that in almost every case the ferric-oxide content of the slag decreased and the ferrous-oxide content increased; but, comparing heat No. $P8$ with heat No. $P15$, which were essentially duplicate experiments, in one case the ferrous-oxide content hardly increased at all, while the ferric-oxide content decreased slightly, whilst in the other the ferric-oxide content decreased and the ferrous-oxide content increased in the same way as in the rest of the experiments, yet the dephosphorisation in both heats was very similar. He wondered what was the explanation of that.

The PRESIDENT (Mr. John Craig, C.B.E.) said he was sure the Meeting would like to convey to the Tata Company its appreciation of the liberty given to Mr. Yaneske to put before it the results of the remarkable investigations and experiments which had been carried out. He thought it was highly commendable that the Company had made that information available to people in Great Britain who were interested in the subject.

He had followed the Perrin process with interest for some time. It seemed to him that the world was wanting better steel and at the same time the supply of good natural ores was becoming exhausted, and it seemed as if by his process Mr. Perrin was going to overcome the shortage by making available for the production of high-grade steel the secondary ores of the world. Whilst Mr. Perrin had not yet perfected his process, the paper opened an avenue for discussion and thought which some of the younger members of the steel industry might follow, and, by improving the Perrin process, they might make up for the world's shortage of good hematite ores, by showing how high-phosphorus ores and impure ores could be used to make high-grade steel.

The paper had appealed to him as one of really great import- ance, and he was sure he was expressing the wishes of all the Members present in asking Dr. Swinden to tell Mr. Yaneske how much they appreciated the care he had taken in submitting the information obtained from the experiments carried out at the Tata Works. He thought the steel trade could prosper best along individualistic lines by a free exchange of information. He was not quite sure that a great national experimental college would ever attain the success which a man would attain who was trying hard to make a good steel to beat a competitor. Everybody's business was nobody's business, and a man who had not to work to a balance sheet could do a great deal of damage to the industry.

Dr. T. SWINDEN (Member of Council, Stocksbridge) said that the author would reply fully to the discussion, but he would like to make some observations on the contributions which had been made.

As to the slag treatment of blast-furnace material before Bes- semerising, raised by Mr. Whiteley, the obvious difficulty was the high silicon content, which would react with the slag and reduce both its basicity and its oxidising power. But, bearing on the point to which Mr. Whiteley had referred in the last paragraph of his contribution, i.e., the treatment of 1.5% phosphorus material, he had intended to imply that it was precisely in that direction that experiments were being made in Britain at the present time.

Mr. Percival Smith had emphasised the important commercial point which had also been referred to by Dr. Hatfield, namely, that the plant in question had been built for a specific purpose. He did not think that he was betraying any confidence in saying that Mr. Mather had explained the position to him as being that the Tata Company had planned to extend its production and that the Perrin process had been regarded as a possible alternative method to the present duplex method. The results of experiments had been such as to make the Company decide to work in the way described, in a works planned essentially for the process.

On the same point he would take Dr. Hatfield's question about

cost. He could not quote the actual figures, but clearly the Company anticipated a reduced cost of production compared with that of its normal duplexing process; otherwise it would not have adopted the Perrin process. The anticipated saving was at least several shillings per ton, and on the scale of production of the Tata Works that would represent a large amount of money.

As to efforts being made on a co-operative scale, he was sure all the Members sympathised with Mr. Percival Smith in his appeal and agreed that a problem of the kind in question merited a large-scale attack; notwithstanding the great efforts that had been made, largely by Dr. Hatfield through the Research Council, he felt that there was room for more work of this character. Mr. Percival Smith, as Chairman of the Open-Hearth Committee, was perhaps in the best position to press for more large-scale co-operative research work to be carried out on a process of this kind.

The furnace for slag melting certainly constituted a problem. The author said in his paper " In order to conduct these experiments, one of the 250-ton basic open-hearth tilting furnces at the duplex plant was employed for melting the synthetic dephosphorising slag whenever suitable opportunities occurred." The lining would be magnesite. In the new plant there were two slag-melting tilting furnaces, each of 50 tons slag capacity, open-hearth design, basic-lined, heated with mixed gas.

He entirely agreed with Mr. Mitchell's commendation of Mr. Perrin's lucidity of thinking and the very clever way in which he had carried out his experimental work.

With regard to the Aston-Byers process, to which Mr. Gerber had referred, that was quite different from the Perrin process. In the Aston-Byers process one was working with an acid slag and one's object was to leave the slag in the metal and not to remove it. The washing process, however, was definitely on the lines of the Perrin dephosphorising process. In fact, the basic idea was very old indeed, and any novelty could lie only in the precise technique with which it was carried out.

Dr. Hatfield's remarks, as he had himself said, referred essentially to a different type of Perrin process, i.e., the deoxidising process. Those who saw that process tried out had been very much impressed by it. They saw 15 tons of metal put into such a highly oxidised state that it would have taken at least half an hour, possibly an hour, to get the bath back into condition in the ordinary way, but they saw the furnace tapped almost immediately and 31 ingots cast in the usual way; they made a full examination of the first, the middle and the last ingot of an alloy steel cast and found them to be very good ingots indeed, very clean and made of really first-class steel. But, having seen all that and having been to a great deal of trouble in consultation with Mr. Perrin and his advisers, he agreed with Dr. Hatfield that it was difficult to visualise the fullest and most proper application of the process in the absence

of a plant designed to do the work on a really properly laid-out scale.

It seemed quite evident from the paper that it was the Fe_2O_3 which supplied the bulk of the oxygen. The fact that a larger proportion of the open-hearth slag was required than of the synthetic slag also depended to a certain extent on the greater amount of silica present, thereby reducing the availability of base for the removal of the phosphorus.

CORRESPONDENCE.

Mr. G. A. V. RUSSELL (Sheffield) wrote that Mr. Yaneske was to be congratulated on bringing forward a paper of such interest as his account of the experiments undertaken at the Tata Works on the dephosphorisation of blown metal by slag treatment in accordance with the method devised by Mr. Perrin at Ugine. Processes like this and the Aston-Byers, in which metal was brought rapidly into contact with chemically active slags more intimate than could be achieved in, say, ordinary open-hearth steelmaking made a strong appeal on technical grounds to those, like the writer, who had had direct experience of the possibilities in speeding up the refining of other metals by analogous means, and it was somewhat disappointing to them to realise that so far the prospect of effecting economic advance in steel production by their aid had not been as great as their technical interest. Now, however, the fact that a new plant to work the process was under construction at the Tata Works must be taken as an indication of the anticipation that under the conditions there the process would justify itself financially. This was all the more interesting as the available hot metal—apart from a rather high silicon content, probably intentional in view of the present duplex operation, and which even if inevitable could be easily reduced by a cheap scale treatment— was one that many operators would regard as an excellent basis for a low-conversion-cost operation by ordinary means, provided that reasonable scrap supplies were available. It was perhaps to the latter factor that the economic attraction of the process in India was due, as, with a widely scattered steel-consuming area like that country, the amount of scrap that could be brought back to a steel plant economically must be limited.

In connection with the new plant to which Mr. Yaneske referred, the writer would like to ask what was the nature of the lining which would be adopted for the 100-ton open-hearth furnaces. Were they to be acid or basic? If the former, was any trouble anticipated from pouring in the hot dephosphorised metal on to the silica lining? The writer presumed that open-hearth slag would be employed as far as practicable in the new operation and

that this would be transferred to the so-called slag mixer as available. What linings would be employed for the dephosphorising ladles in the new plant?

Mr. VERNON HARBORD (London) wrote that he had read Mr. Yaneske's paper with the greatest interest. It was very rarely that it was possible to carry out an experimental investigation on the scale recorded, and these experiments were of exceptional value, owing to the very systematic way in which they had been carried out, and the difficulties met with faced and overcome until a satisfactory method of operating on a commercial scale had been established. The author was to be congratulated on having presented to the Institute a paper of such great value.

With the pig iron relatively low in phosphorus which was being used at the Tata Works, the basic Bessemer process was impossible, and the alternatives were :

(1) To treat the mixer metal direct by the basic open-hearth process.

(2) To decarburise in the acid Bessemer converter, dephosphorise by the Perrin process and cast into ingots as described in the paper.

(3) To dephosphorise the desiliconised and partially decarburised metal by the Perrin process, and finish in the acid or basic open-hearth furnace.

(4) To dephosphorise the mixer metal by the Perrin process without desiliconising, and decarburise and finish in the acid or basic open-hearth furnace.

(5) To desiliconise in an acid Bessemer converter, dephosphorise by the Perrin process, and produce finished steel by finally decarburising in an acid Bessemer converter as proposed by Mr. Perrin.

The experiments showed that when using a pig iron containing from 0.3% to 0.4% of phosphorus, decarburised in an acid Bessemer converter to about 0.1% of carbon, the phosphorus could be satisfactorily removed by the Perrin process, and a rimming steel and probably a semi-killed steel could be produced, equal in quality to that produced by the basic Bessemer process.

Although the maximum phosphorus in the Tata experimental work was 0.4%, it was quite possible that higher-phosphoric pig iron could be successfully treated by increasing the quantity of slag used and varying its composition. If this were demonstrated it might be possible to treat by the Perrin process pig iron which was just too low, or even high enough in phosphorus for basic Bessemer practice, to compete with basic Bessemer steel, and in such cases the dephosphorising by the slag would take the place of the after-blow in the basic Bessemer process, and one would expect that there would be less danger of over-oxidation. It

would then be a question of which was the more economic process, the basic Bessemer, or the acid Bessemer, plus the Perrin process under the particular conditions prevailing.

The use of the finished slag from the basic open-hearth furnace in whole or in part instead of the synthetic slag was a very definite step forward in the economy of the Perrin process. By maintaining a supply of liquid slag in a special furnace, the composition of which could be modified by suitable additions of oxides of iron and lime, there seemed no reason why dephosphorisation equal to that obtained by the synthetic slag should not result.

He had tried to trace the effect of variations in the percentages of silica, oxides of iron and lime in the slags used on the more or less complete removal of the phosphorus, but there were not a sufficient number of heats recorded in which the same percentage weight of slag of identical composition was used to do this, but with the larger number of heats which the author must have recorded, this might be possible.

He would like to ask the author if he had carried out any experiments in which the FeO was largely in excess of the Fe_2O_3. In nearly all the examples given, the Fe_2O_3 was greatly in excess of the FeO, and with the exception of basic open-hearth slags there was only one in which FeO predominated. In many respects the last recorded experiment, $P5$, in which desiliconised metal containing 3.25% of carbon and 0.295% of phosphorus was dephosphorised, and the metal after treatment contained only 0.035% of phosphorus and 2.14% of carbon, was the most interesting to the writer. This took one back to the experiments of Sir Lowthian Bell, recorded in a paper read before the Institute in 1878, and which, he thought, were the first published experiments on the washing of pig iron.

The special object of those experiments was to remove the phosphorus and silicon while retaining the carbon, to produce a low-silicon, low-phosphorus iron to compete with the plate iron produced in the refinery from Cleveland iron used for making high-quality puddled iron ; alternatively to produce an iron sufficiently low in phosphorus for use in the acid Bessemer process, as at that time the basic process had not been developed.

In those experiments rich oxides of iron were first melted in a puddling furnace, but later in a special furnace designed for the purpose, and molten pig iron was poured into the fluid slag.

The average composition of the pig iron was as follows :

Carbon.	Phosphorus.	Silicon.
3.7% approx.	1.5%	2.0%

The phosphorus removed varied from 80% to 89% and in some cases was reduced from 1.5% in the pig to 0.089% after treatment, whilst in other cases as much as 0.29% remained in the treated iron. As little carbon as possible was removed, generally

under 10%, to maintain the fluidity of the metal, but occasionally as much as 15% was eliminated.

The average analyses of the iron-oxide slags used were as follows :

					Before adding the Metal.	After adding the Metal.
Fe_2O_3	.	.	.	.	$26\cdot642\%$	$6\cdot913\%$
FeO	.	.	.	.	$45\cdot389\%$	$57\cdot014\%$
SiO_2	.	.	.	.	$19\cdot266\%$	$23\cdot579\%$
P_2O_5	.	.	.	.	$1\cdot972\%$	$4\cdot578\%$

The highest and lowest limits in silica and oxides before adding the metal were :

					Lowest Limit.	Highest Limit.
SiO_2	.	.	.	.	$9\cdot78\%$	$25\cdot22\%$
FeO	.	.	.	.	$24\cdot84\%$	$64\cdot20\%$
Fe_2O_3	.	.	.	.	$8\cdot14\%$	$49\cdot01\%$

Under the low-temperature conditions lime was not necessary, as phosphate of iron was practically stable at the temperature of molten pig iron, even in the presence of carbon, and it was only at the high temperature of the Bessemer converter or open-hearth furnace that lime in considerable quantity was essential to form a stable phosphate.

Although when using Bessemer decarburised metal the high temperature of the blown metal will necessitate the presence of an appreciable percentage of lime, he did not think this was so high as some remarks by the author would seem to suggest, and he would expect that much less lime than appeared in most of the slag analyses would effectively hold the phosphorus in the slag. If the lime were to an appreciable extent replaced by oxide of iron and possibly some manganese oxide, the greater fluidity of the slag would probably increase its activity as a dephosphoriser, and, provided that sufficient lime were present to hold the phosphorus, he would expect better results than with a slag containing a higher percentage of lime. The fact that basic Bessemer slag with 12–14% of silica and 45–47% of lime frequently contained 16– 17% of P_2O_5 indicated that a much lower percentage of lime than that shown in the analyses of the Perrin slags would be effective.

Was the necessity for desiliconising before dephosphorising really so essential as the author seemed to think ? In view of results obtained by Sir Lowthian Bell with 2% silicon pig iron, he thought it should be possible with a slag of suitable composition, using mixer metal containing 1% of silicon and 0·3–0·4% of phosphorus, without a preliminary desiliconisation to remove the phosphorus to 0·03–0·04% and the carbon to, say, about 2%. If this could be done the possibilities of operating the Perrin process would be greatly increased, as it would enable the dephosphorised mixer metal, with, say, about 2% of carbon, to be taken direct to either the acid open-hearth or the basic open-hearth furnace for the production of finished steel without the cost of a preliminary desiliconisation.

Mr. R. MATHER (Tata Iron and Steel Co., Ltd.) wrote that he had been privileged to see the account of the verbal discussion and also the written contributions. The questions raised would no doubt be dealt with more competently by Mr. Yaneske, whose reply would, it was hoped, be available for publication in the succeeding volume of the *Journal*. In the absence of the complete records of the trials summarised in the paper, the writer would confine himself to some of the more general issues raised.

The background of Mr. Yaneske's work should be realised. The Jamshedpur Works were producing over one million tons of ingots yearly. Of this total, about two-thirds were made in the duplex plant (described by Mr. Yaneske in 1927) and the remaining third in a basic open-hearth plant of conventional, though old, type. No scrap was brought into the works from outside. The steel must therefore be made entirely from pig iron, the nature of which was described in the paper, and from the scrap produced in the works in the ordinary course of operations. This scrap was used in the open-hearth plant, practically none being used in the duplex process. The steel was used for the production of bars, sheets (black and galvanised), structural sections, rails, tin-bar, plates and billets. Steel would very shortly be required for the manufacture of wheels, tyres and axles, and at a later date for tube strip. Much the greater part of the steelmaking was based on compliance with British Standard or similar specifications for mild steels. Small quantities of low-alloy high-tensile and similar semi-special steels were made. The production of high-alloy steels was a development now in progress.

When Mr. Perrin's processes came to the notice of the Company it was quickly obvious that the dephosphorisation process offered greater possibilities of usefulness than the deoxidation process. Attention was therefore concentrated on the former, with the results set out in the paper. The most favourable outcome would have been its application to the duplex plant as it now stood. This was not found practicable, largely owing to the insufficient height of fall from the converters, as installed, to ladles on the track below them. The Company, however, wished to increase its ingot capacity. As soon as it was clear that dephosphorisation by the process was effective, its application in a specially designed plant became a matter for practical consideration. The very skilful work of Mr. Yaneske and his immediate associates showed that the technical difficulties could be overcome.

A critical study of all the factors affecting the rate of output and cost showed, *for the conditions existing at Jamshedpur*, that :

(a) The fairly high tonnage of ingots required could be obtained at a lower capital cost than would be possible by any other means ;

(b) the production cost per ton of ingots would be lower than by any other process ;

(c) the reduction of cost under (b) would give a very satisfactory return on the capital outlay under (a);

(d) the advantages under (a) and (b) of the proposed process over other processes would increase if, in the course of future developments at the works, the plant had to be extended for a still larger output;

(e) the process offered the only practical (and a very economical) basis for the manufacture of acid steel from Indian materials, and an elastic and economical starting point for the manufacture of semi-special steels and indeed of high-grade steels.

It was not possible at present to give more details in support of these findings than were contained in the paper. They were, however, not arrived at hurriedly. The Company's final decision to build a large new plant to operate the process sufficiently indicated its conviction that the process was sound technically and that the savings were substantial.

Questions had been asked about the functioning of the process under conditions differing in various ways from those at Jamshedpur. The trials made there could not be expected to produce information which would do more than act as a pointer to the results obtainable under different conditions. Mr. Yaneske had rightly confined himself to describing what he did and to mentioning the practical deductions drawn by himself and the officials of the Company for their own circumstances. He made no claim about the operation of the process under other conditions. Equally, however, he did not claim to have exhausted the possibilities of the process. On such matters as the dephosphorisation, for example, of metal containing 1.5% of phosphorus, it was doubtful whether any definite pronouncement could be made except after actual trials. The present writer would merely comment that it would be unfortunate that those actually interested should allow the answer to go by default if an affirmative answer would open up economically valuable possibilities.

Mr. Yaneske had also made no wide claims about the quality of the steel produced. His work had shown the quality to be entirely satisfactory for tin-bar, sheet-bar, dead soft bar, &c. Possibilities of a wider application were certainly indicated in the paper. It was reasonable to expect that the greater facilities provided by the operation of the new plant would enable the question of the wider range of quality to be settled definitely on the basis of actual experience. The new conditions might also facilitate work which would throw light on some of the other questions raised.

Some of the speakers had referred to the importance of the height of fall of the metal into the slag. An almost equally important factor was a regular and sufficiently high temperature. With a proper combination of height of fall and temperature of metal

and slag, the reaction was very quick and regular. The temperature at which the metal and slag were brought together obviously required good timing of the operations and of handling throughout the plant, but the problem was not appreciably greater than in other two-stage processes, such as the existing duplex process; the very large outputs which were being obtained by such processes showed that good timing was quite practicable.

The writer was more fully aware than most others of the many difficulties which Mr. Yaneske and his immediate associates in the work had had to surmount. He wished to add his personal tribute to the technical skill and resource, and to the energy and determination which they had shown in bringing an arduous series of trials to the point at which definite and constructive results of great value were obtained. He thought it would be in no way derogatory to the value of Mr. Perrin's great contribution to metallurgical practice if the process as worked out at Jamshedpur came to be known as a whole as the Perrin-Yaneske process.

The author's reply had not been received at the time of going to press, but it is hoped to publish it in the next volume of the *Journal.*

THE IRON-PLATING OF SPECIMENS FOR MICROSCOPICAL EXAMINATION.*

By E. A. JENKINSON, B.Sc. (National Physical Laboratory, Teddington, Middlesex).

(Figs. 1 to 12 = Plates I. and II.)

Summary.

This paper gives an account of a method of supporting fractured surfaces of creep and tensile test-pieces so that longitudinal sections can be prepared for microscopical examination right up to the fracture.

After a brief discussion of the disadvantages of first a fusible alloy mounting and then a thick copper electrodeposit, experimental work on the production of heavy electrodeposits of iron with suitable qualities is described. The general effect of temperature and current density on the microstructure of the plating is illustrated by micrographs.

It has been found possible to obtain suitable deposits when employing a temperature of 85° C. and current densities between 5 and 20 amp. per sq. ft.

Introduction.

In the investigation of the deformation of metals at high temperatures [1] longitudinal sections of fractured test-pieces were examined microscopically to determine the type of fracture and the changes in structure close to the fracture and along the length of the test-piece. It was found necessary to give some form of support to the fractured surface so that flat polished sections could be prepared and examined right up to the fracture.

A fusible-alloy mounting was unsuitable for two reasons. Its softness in comparison with the test-piece made it difficult to retain a truly flat surface in polishing, and the specimen in the vicinity of the fusible metal was not etched so easily as the rest of the material. A thick electrodeposit of copper was next used. Some previous workers [2, 3, 4] in the Metallurgy Department, National Physical Laboratory, had employed electrodeposited copper or a combination of electrodeposited copper and iron for the protection of surfaces and fractures. Copper was readily deposited and heavy layers were easily obtained on the specimens. Experience with this method led to the conclusion that it possessed disadvantages similar to those already found when using fusible metal, but to a somewhat less extent. There were also the additional disadvantages that the

adherence of the copper plate was not always good and that two solutions were needed : First an alkaline cyanide bath at a low current density and then an acid sulphate one, which could not be used directly on the iron specimen owing to chemical action.

Iron deposition was then tried, and after some experimental work it was found possible to plate on to fractures a heavy electro-deposit of iron which had suitable qualities for the subsequent microscopical examination. The qualities required were : (a) Toughness, (b) firm adherence, (c) absence of gas cavities, (d) uniform thickness of approximately 0·020 in. and (e) ability to permit uniform etching of the specimen. The present paper gives an account of the experiments carried out to obtain this type of deposit.

Experimental Work.

The electrolytic bath used was the same as that employed by Cain, Schramm and Cleaves [5] and Tritton and Hanson [6] in the preparation of electrolytic iron and consisted of :

Ferrous chloride	.	.	.	288 g.
Sodium chloride	.	.	.	57 g.
Distilled water	.	.	.	1000 c.c.

A special grade of ferrous chloride containing 0·0032% of nickel, 0·0076% of manganese and 0·001% of phosphorus was employed together with sodium chloride of " Analar " purity. Solutions were prepared by adding the ferrous chloride and the sodium chloride to distilled water and allowing them to dissolve cold. Small amounts of ferric chloride were removed by filtering before use. At the high temperatures at which the bath was operated loss by evaporation was a serious factor, and a device was used to maintain the bath at constant level by the addition of distilled water.

The plating equipment consisted of a glass vessel of 400 c.c. capacity provided with a small electric hot-plate to maintain the temperature. The specimen formed the cathode, which was suspended from a spindle rotating at approximately 50 r.p.m. The anode consisted of a piece of Armco ingot iron plate, $4 \times 1 \times \frac{1}{2}$ in., bound with linen tape to prevent sludge from entering the bath. The following ranges of conditions were examined :

(1) Current density, 5 to 35 amp. per sq. ft. of cathode.
(2) Temperature, 70 to 100° C.

Specimens plated were fractured halves of creep or tensile standard round test-pieces. In most cases the tests had been conducted *in vacuo*, the fractures being bright, but in a few cases tests had been made in air and the fractures were then more or less badly oxidised. Materials plated included Armco ingot iron, high-purity iron and steels containing from 0·4% to 1·1% of carbon. Specimens were plated in the condition in which they were removed from the testing unit without washing, cleaning or handling in any way.
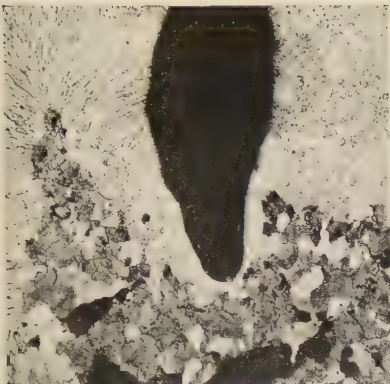
PLATE I.

FIG. 1.—1·1% Carbon Steel, plated at 70° C., c.d.
12 amp. per sq. ft.   × 150.
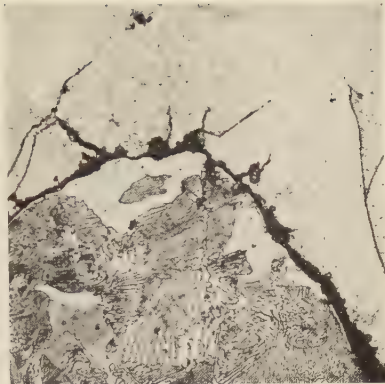
FIG. 2.—1·1% Carbon Steel, plated at 75° C., c.d.
26 amp. per sq. ft.   × 500.
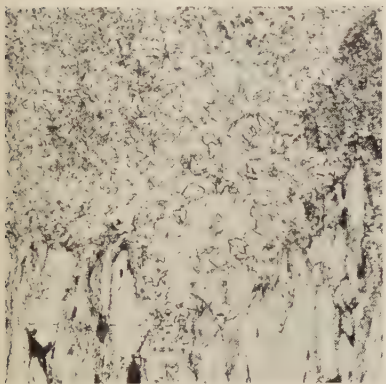
FIG. 3.—Armco Ingot Iron, plated at 75° C., c.d.
7·6 amp. per sq. ft.   × 150.
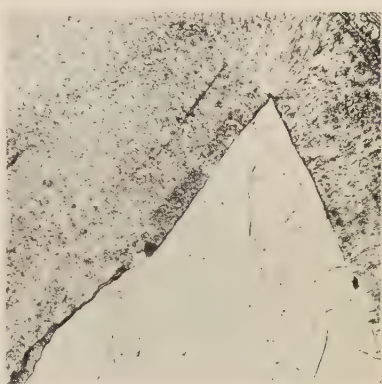
FIG. 4.—High-Purity Iron, plated at 75° C., c.d.
15 amp. per sq. ft.   × 150.
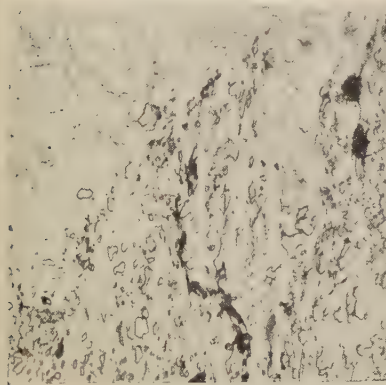
FIG. 5.—1·1% Carbon Steel, plated at 80° C., c.d.
9 amp. per sq. ft.   × 500.
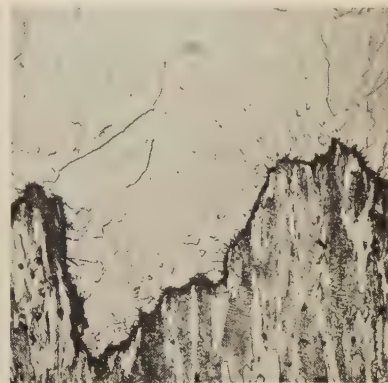
FIG. 6.—0·57% Carbon Steel, plated at 80' C., c.d.
13 amp. per sq. ft.   × 500.

(Micrographs reduced to two-thirds linear in reproduction.)

PLATE II.

Fig. 7.—1·1% Carbon Steel, plated at 85° C., c.d.
6 amp. per sq. ft. × 500.
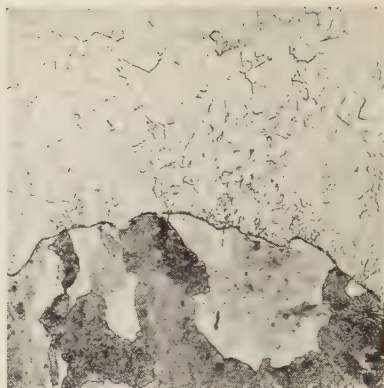
Fig. 8.—0·86% Carbon Steel, plated at 85° C., c.d.
19 amp. per sq. ft. × 500.
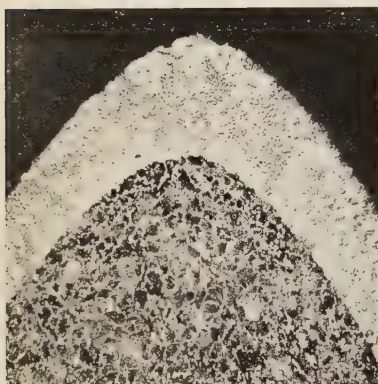
Fig. 9.—0·57% Carbon Steel, plated at 85° C., c.d.
9 amp. per sq. ft. × 50.
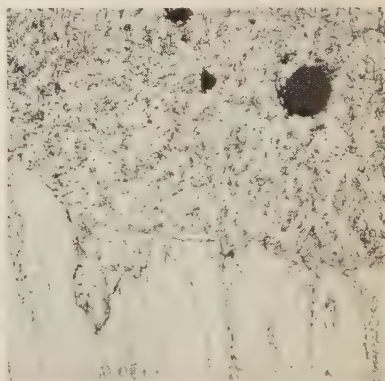
Fig. 10.—High-Purity Iron, plated at 85° C.; c.d.
27 amp. per sq. ft. × 500.
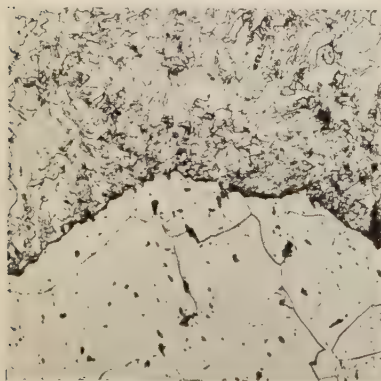
Fig. 11.—High-Purity Iron, plated at 95° C., c.d.
22 amp. per sq. ft. × 150.
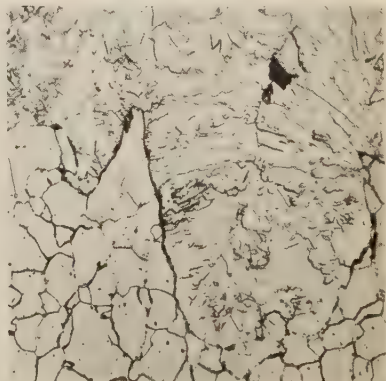
Fig. 12.—High-Purity Iron, plated at 95° C., c.d.
34 amp. per sq. ft. × 500.

(Micrographs reduced to two-thirds linear in reproduction.)

The fractures of most of the test-pieces were very irregular, but in the case of a few of the high-temperature creep-test specimens (at 850° C. and 950° C.), the fractures were smooth and rounded. Examples of this type are given in the photomicrographs (Figs. 2, 8, 9 and 11).

Several hundred heavy iron deposits were prepared. The general effect of temperature and current density on the microstructure of the plating is illustrated by Figs. 1 to 12. The electrodeposit forms the upper portion of the micrograph in every case.

Description of Microstructures.

Iron deposited at temperatures below 70° C. took up large quantities of hydrogen, giving a very rough, brittle and friable electrodeposit. Some of the hydrogen released as plating proceeded remained in contact with the cathode and ultimately cavities were produced where these gas bubbles remained (Fig. 1). Gas cavities could be produced at higher temperatures, but only at high current densities, and even then not to the same extent (Fig. 10). Brittleness in a deposit led to internal cracking (Fig. 2). Between 70° and 80° C. the deposits obtained at current densities of 7·5 to 26 amp. per sq. ft. had a very fine grain size (Figs. 1 to 4), but suffered from excessive numbers of gas cavities, most of which, however, were small. At temperatures between 80° and 100° C. the deposits were fine-grained and free from cavities except at the highest current densities employed (Fig. 10). The line of demarcation between electrodeposit and specimen was very slight, and specimens in the unetched condition showed none ; on etching, the different structures of the basis metal and the electrodeposit gave adequate definition between the two. An example of this is given in Fig. 5, where the basis metal consists of a spheroidised steel with a ferrite matrix.

In general, adherent deposits were obtained irrespective of surface conditions. Surface oxidation of the original material tended to increase the risk of gaseous cavities at the higher temperatures, but, provided that low current densities were employed, smooth deposits free from gas cavities were obtained (Fig. 6). In several cases where heavy oxidation had taken place adherent smooth deposits were formed. A good deposit was obtained most readily with a rough bright surface (Figs. 3, 7 and 9).

Figs. 11 and 12 illustrate deposits produced at 95° C. with relatively high current densities. They were not so free from inclusions as those formed at 85° C.

Columnar crystals were almost entirely absent from the deposits in the present work, except perhaps in those formed at 95° C. (Fig. 12). Probably at the low current densities employed the grains were formed sufficiently slowly to permit more or less uniform growth.

Firmly adherent deposits were obtained at all current densities (5 to 35 amp. per sq. ft.) between temperatures of 70° and 100° C. except

in the case of a specimen plated at 75° C. with a current density of 26 amp. per sq. ft. (Fig. 2). This was a special case, in that the fracture was blunt and not rough and jagged. At higher temperatures and lower current densities, however, blunt fractures were successfully plated (Figs. 8 and 9).

Conclusions.

It has been found possible to obtain uniform and adherent deposits free from gas cavities both on bright test-pieces and on those which have suffered some degree of oxidation.

Plating at temperatures below 80° C. tends to produce gas cavities, brittleness and internal cracking of the deposit. At 85° C. the optimum conditions exist and the deposit is tough, very adherent and free from defects such as gas cavities. At higher temperatures the bath is more difficult to operate, owing to excessive evaporation, and the deposits are somewhat coarser and less clean than those produced at 85° C. It has been found that high current densities tend to produce gas cavities and fine grain size with consequent brittleness. The best conditions of current density are found to be from 5 to 20 amp. per sq. ft.

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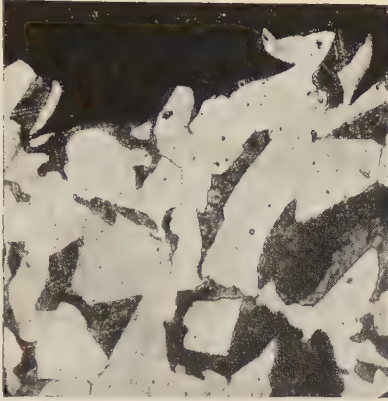
PLATE II A.

FIG. A.—Fractured Edge of a 0·25% Carbon-Steel Tensile Specimen.   × 500.

FIG. B.—Fractured Edge of a 3% Nickel-Steel Tensile Specimen.   × 500.

(*See* L. Smith's contribution.)

[*Correspondence on Jenkinson.*

CORRESPONDENCE.

(Figs. A and B = Plate IIA.)

Mr. L. SMITH (Billingham) wrote that the results obtained by Mr. Jenkinson were undoubtedly good and were a great improvement on those obtained by mounting specimens in fusible metal. It was, however, rather surprising that no mention was made in the paper of plastic mounting materials. The use of synthetic resin for mounting microsections had been standardised in the Billingham laboratories for some years and had been fully justified by the excellence of the results obtained and the saving in time. The writer would suggest that the results were at least as good as, if not better than, those obtained by iron-plating. The two photomicrographs Figs. A and B illustrated the results obtained with samples similar in nature to those which were used by Mr. Jenkinson. The samples were mounted and polished by a sixteen-year-old boy. The time taken to carry out the plating of a sample to give a coating of satisfactory thickness was not mentioned in the paper, but it was assumed that it would be considerable. A single sample could be mounted in plastic in 20 min., while if several samples were mounted consecutively the average time per sample was less than 10 min.

The technique employed was very simple. A commercial press was used at Billingham, but an efficient one could easily be constructed from a hydraulic car-jack with some modification. The equipment included a mould and plunger, round which fitted an electric heater. The sample was placed in the mould, the moulding powder was poured in, and the plunger, into which fitted a thermometer, was pushed into the mould. The mould was then heated to 140° C. and at the same time the pressure was gradually raised to 1 ton per sq. in. The pressure and temperature were maintained for a curing time of five minutes or so, depending on the powder used, and the moulding was then ejected hot. This technique applied only to the particular powder used by the writer, which was of the thermo-setting phenol-formaldehyde type.

The resulting moulding was hard enough to give excellent support to the sample, did not clog the emery paper, was unaffected by all but the most severe etching reagents, formed a good bond with the specimen, and did not give false etching effects due to the formation of a galvanic couple with the specimen. The method suffered from the disadvantage that it involved heating the specimen to 140° C., but in the vast majority of cases this was of little moment. For most of the writer's work the method described above was very successful, but where a particularly sharp edge was required it had been found that the incorporation of 25% of iron filings in the moulding powder increased the hardness of the moulding, resulting in even better support of the edge of the sample.

AUTHOR'S REPLY.

The AUTHOR replied that Mr. Smith's description of the technique used at Billingham was very interesting.

Plastic moulding materials had been used in the Metallurgy Department of the National Physical Laboratory for a number of years and a description of the methods employed was given in the *Journal of the Iron and Steel Institute*, 1932, No. II., p. 184, in the Appendix by T. W. Lewis.

He did not find this method particularly suitable for the mounting of fractured test-pieces, and for this reason developed the process of iron-plating, the specimen being subsequently mounted in plastic compound.

THE CRYSTAL STRUCTURE OF CEMENTITE, Fe₃C.*

By H. LIPSON, D.Sc., and N. J. PETCH, B.Sc., B.Met. (Cavendish Laboratory, Cambridge).

Summary.

Previous workers on the structure of cementite have located the iron atoms accurately, but have failed to detect the carbon atoms. On the basis of space available, two alternative sets of sites are possible; one of these is more probable, as it agrees better with the usual size of the carbon atom.

By direct calculation of the electron density in two different planes in the unit cell, using accurately measured intensities of X-ray reflection, the present authors have found the positions of the carbon atoms. They agree very well with the more probable of the two sets of positions previously suggested.

A description of the structure is given, with a discussion of its possible relation to the structures of ferritic and austenitic iron.

Introduction.

THE structure of cementite has been the subject of two main in-vestigations in the past. Westgren and Phragmén [1] determined the unit cell, and from their data Hendricks [2] found the space group and the positions of the iron atoms. With regard to the carbon atoms he did no more than suggest possible sites, without attempting to justify them on the basis of X-ray intensities. West-gren, [3] however, pointed out that the carbon atoms on these sites would have to possess rather smaller radii than usual, and showed that there were alternative positions which would allow the intro-duction of carbon atoms of the normal size. He also showed that the X-ray intensities agreed rather better with his structure than with Hendricks', but was careful to state that the agreement was not sufficient to prove the correctness of the structure.

Both Hendricks and Westgren used only visual estimates of intensities, in which the successive classes differed by a factor of the order of 2. Since the carbon contributes only about 7% of the total number of electrons, the possibility that it may produce a difference of even one class in intensity is very remote. It is therefore essential that accurate measurements of intensity be used if the carbon atoms are to be located. Even with accurate intensities it was found that the carbon contributions would still be of the same order as the experimental error, and, moreover, of the same order as the changes due to the possible errors in the parameters quoted by Westgren.

Thus, a completely objective survey of all the intensities is necessary in order to establish the carbon positions.

The best method of providing this survey is that of Fourier synthesis,[4] which gives the electron density at every point in the unit cell directly from intensity measurements. From these measurements can be derived the numerical values of the structure amplitudes, but the signs of these structure amplitudes can be obtained only from a knowledge of the positions of the iron atoms. No assumptions, however, need be made about the positions of the carbon atoms, since any structure amplitude which could be reversed in sign by the carbon contribution would give an intensity too small to be observed. Thus the results obtained must be quite independent of any preconceived ideas about the positions of the carbon atoms.

Although Fourier methods can give the electron density in three dimensions it has been usual to reduce the formulæ to two dimensions in order to simplify the calculations. This then gives the projection of the electron density on a plane. In the case of cementite this would mean that a projection would contain twelve iron atoms and four carbon atoms, and thus the latter might be very difficult to detect. If, however, one sums the three-dimensional series, one can be sure that none of the atoms will come so close to another that it cannot be observed. As will be shown below, it is not necessary to sum the series at every point in the unit cell in order to establish the positions of the carbon atoms, so that the work can be kept within reasonable bounds.

Three-dimensional Fourier synthesis requires the observation of all the intensities within a given value of the Bragg angle, θ. The most convenient way of observing these is by the Debye-Scherrer powder method. The main objection to this method is the lack of resolution of the spectra, but since the unit cell of cementite is not large this objection is not serious, and it was overcome to a considerable extent by using a large camera, of diameter 35 cm.

Experimental Details.

The specimen was prepared for the authors by Dr. J. Taylor, of King's College, Newcastle-upon-Tyne, by passing carbon monoxide over ferric oxide at 550° C. This gave a specimen of very fine powder that yielded an X-ray photograph of which all the lines could be indexed on the basis of the unit cell of cementite, although the lines were not very sharp. Attempts at annealing at 600° C. or higher always resulted in partial decomposition, mostly into ferrite but sometimes into another structure which was probably Fe_2C [5]; but the cementite lines were also sharpened up. The measurement of intensities was therefore carried out on a photograph of the unannealed specimen, the measurement of spacings on that of a specimen annealed at 600° C. for 17 hr.

The powder was sieved through a wire mesh of 380 to the inch, and inserted in a fine borosilicate glass tube. This type of specimen was made for the intensity work in the 35-cm. camera because the evacuation of the camera (rendered necessary owing to the absorption by the air in a camera of this size) usually spoiled the shape of a normally made specimen.[6] A photograph was taken with filtered cobalt radiation, with an exposure of 200 milli-amp-hr. A photograph of the annealed specimen was taken with manganese radiation, in a 19-cm. dia. camera, and from this was made an accurate determination of the unit cell dimensions.

Determination of the Structure.

The structure is orthorhombic, and the dimensions of the unit cell at 21° C. are :

$$a = 4 \cdot 5144 \text{ Å}.$$
$$b = 5 \cdot 0787 \text{ Å}.$$
$$c = 6 \cdot 7297 \text{ Å}.$$

(These values are probably accurate to $0 \cdot 01\%$). This unit cell contains twelve iron atoms and four carbon atoms. The space group is *Pbnm*, of which the general equivalent points are :

$(x, y, z), (x, y, \frac{1}{2} - z), (\frac{1}{2} - x, \frac{1}{2} + y, z), (\frac{1}{2} - x, \frac{1}{2} + y, \frac{1}{2} - z),$
$(\bar{x}, \bar{y}, \bar{z}), (\bar{x}, \bar{y}, \frac{1}{2} + z), (\frac{1}{2} + x, \frac{1}{2} - y, \bar{z}), (\frac{1}{2} + x, \frac{1}{2} - y, \frac{1}{2} + z).$

The important symmetry elements are the centres of inversion at :

$(0, 0, 0), (0, 0, \frac{1}{2}), (\frac{1}{2}, \frac{1}{2}, 0), (\frac{1}{2}, \frac{1}{2}, \frac{1}{2})$ . . . . *a* positions,

the centres of inversion at :

$(\frac{1}{2}, 0, 0), (\frac{1}{2}, 0, \frac{1}{2}), (0, \frac{1}{2}, 0), (0, \frac{1}{2}, \frac{1}{2})$, ... *b* positions,

and the planes of symmetry at $z = \frac{1}{4}$ and $z = \frac{3}{4}$, which give equivalent points at :

$(u, v, \frac{1}{4}), (\frac{1}{2} - u, \frac{1}{2} + v, \frac{1}{4}), (u, v, \frac{3}{4}), (\frac{1}{2} + u, \frac{1}{2} - v, \frac{3}{4})$ . . *c* positions.

It is upon one of these sets of four-fold positions that the carbons must lie. Thus, a calculation of the electron density at all points in the planes $z = 0$ and $z = \frac{1}{4}$ should establish the positions of the carbon atoms without any *a priori* assumptions.

The data used in the calculations are shown in Table I. The structure amplitudes (F) were obtained directly from the observed intensities without any correction for absorption, since this correction was found to be almost constant over the small range of θ used, and were placed on an absolute scale by comparison of the intensity 121 with that calculated from the known positions of the iron atoms. The lines bracketed together in the Table are those which were not resolvable from each other with the apparatus used, and it will be seen that only in three cases had any serious assumptions to be made in allotting to the various lines their components of the total intensities. The assumption made was that the components were proportional to the ratios given by the iron parameters of Westgren, and thus no assumption about the carbon

TABLE I.—*Comparison of Calculated and Observed Structure Amplitudes.*

h	k	l	Structure Amplitude, F.		h	k	l	Structure Amplitude, F.	
			Calc.	Obs.				Calc.	Obs.
1	0	1	2·6	...	2	2	1	8·6	7·6
{1	1	0	$\overline{1·0}$	...	1	3	0	17·7	19·1
{0	0	2	2·8	...	1	2	3	3·9	5·6
1	1	1	$\overline{1·4}$	...	1	3	1	$\overline{6·4}$	7·0
0	2	0	$\overline{7·8}$	9·8	2	1	3	$\overline{2·5}$	4·6
{1	1	2	9·9	9·4	{2	2	2	10·9	9·7
{0	2	1	$\overline{13·6}$	13·4	{1	1	4	4·6	5·6
2	0	0	$\overline{20·2}$	20·5	3	0	1	$\overline{0·4}$	...
1	2	0	$\overline{12·6}$	14·4	3	1	0	$\overline{2·8}$	...
1	2	1	17·6	16·9	1	3	2	1·6	...
2	1	0	26·5	25·6	3	1	1	$\overline{6·5}$	7·0
0	2	2	$\overline{24·9}$	25·2	0	2	4	10·3	11·0
1	0	3	$\overline{35·0}$	32·6	{2	3	0	0·1	...
2	1	1	16·2	17·3	{2	0	4	$\overline{3·0}$	...
2	0	2	$\overline{4·8}$	...	{2	2	3	3·3	...
1	1	3	15·1	14·0	1	2	4	5·7	4·8
1	2	2	$\overline{18·0}$	16·2	{2	3	1	0·9	...
2	1	2	11·9	10·8	{3	1	2	17·2	14·0
{2	2	0	2·5	...					
{0	0	4	13·1	13·5					
{0	2	3	$\overline{13·7}$	13·0					

positions was involved. It will be seen that the *F* values so obtained agree with the calculated within the experimental error.

It is obvious that the series is insufficiently convergent; the sum of such a series will show marked diffraction effects,[7] which may tend to mask the detail sought. This may be overcome by introducing an arbitrary temperature factor of the form $e^{-B\sin^2\theta}$ into the intensities. In the present case it was found that a factor $e^{-3\sin^2\theta}$ introduced into the *F* values made the series sufficiently convergent.

Figs. 1 and 2 show the electron density in the two planes $z = 0$ and $z = \frac{1}{4}$, calculated in this way. The four large peaks in Fig. 1 are sections of the iron atoms not quite through the centres. It will be observed that there are small peaks also in the *a* positions, but none in the *b* positions. In Fig. 2 there are two large peaks representing sections through the centres of iron atoms, and in addition there are peaks at the points *c*. These are much larger than the peaks at *a*, but it is necessary to make electron counts in order to
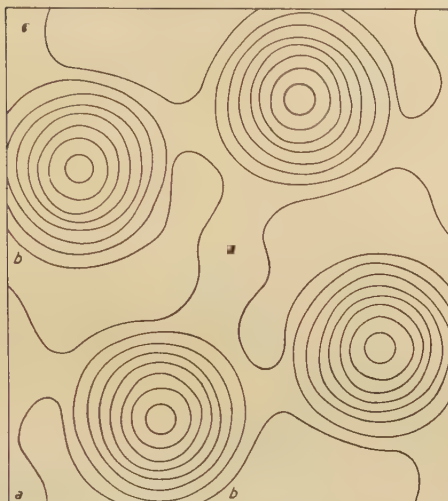
FIG. 1.—Electron Densities in the Plane $z = 0$.   Contours drawn at intervals of one electron per cubic Ångstrom unit.
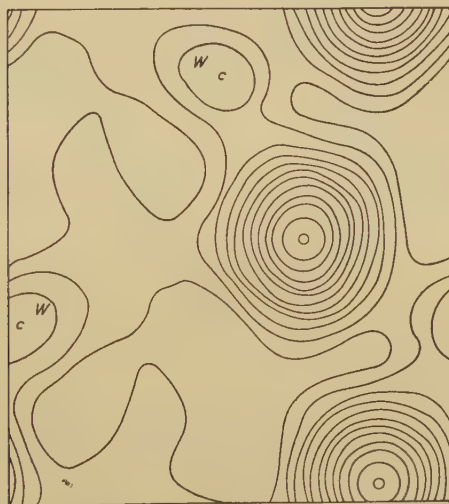
FIG. 2.—Electron Densities in the Plane $z = \frac{1}{4}$.   (Contours as in Fig. 1.)

establish whether either of them is of the right order of size to represent a carbon atom. The counts were made in the following way : The radial distribution $\rho(r)$ of the electron density was obtained from the section, taking directions which did not approach another atom or which abutted any irregularity. From this the number of electrons is given by :

$$4\pi \int_0^a \rho(r) r^2 dr.$$

r is measured from the highest point, and a is the value of r at which $\rho(r) = 0$. The integral may be evaluated graphically.

Using these methods the electron contents of the peaks were found to be :

Peak at a position	0·75 electrons,
peak at c position	4·7 electrons,
iron atom at $z = \frac{1}{4}$	23·1 electrons.

This latter serves as a check, since an iron atom should contain twenty-six electrons. Since the carbon atom contains six electrons it will be seen that it is definitely established that the a peak is too small to be representative of a carbon atom, whereas the c peak is about the right size.

The c peak has parameters $u_1 = 0·47$, $v_1 = \overline{0·14}$, which are very near to the values, $0·43$, $\overline{0·13}$, suggested by Westgren; this latter position is marked W in Fig. 2. It is not claimed that the position given by the Fourier synthesis is more accurate than that deduced by Westgren from spatial considerations.

Attempts were made to improve the agreement between calculated and observed intensities by adjusting the parameters which fix the iron positions. The only change from Westgren's values which seemed definitely indicated was an increase in y. The parameters finally chosen were :

8 Fe at $x = 0·333$, $y = 0·183$, $z = 0·065$;
4 Fe at $u = \overline{0·167}$, $v = 0·040$;
4 C at $u_1 = 0·47$, $v_1 = \overline{0·14}$.

The parameters of the carbon atoms must be regarded as being only approximate; the others are probably accurate to $0·005$, which means that the distances between the iron atoms are probably accurate to $0·05$ Å.

The agreement between calculated and observed values of F is shown in Table I.; the atomic-scattering-power curves used are those given in the International Tables,[8] with allowance for the depression due to the absorption edge effect.[9] It is interesting to note that the mean difference between calculated and observed F values is $1·13$; the mean carbon contribution is only slightly greater than this, $1·24$.

The Structure.

The structure may be described as an almost close-packing of iron atoms, with carbon atoms in the interstices. That it is
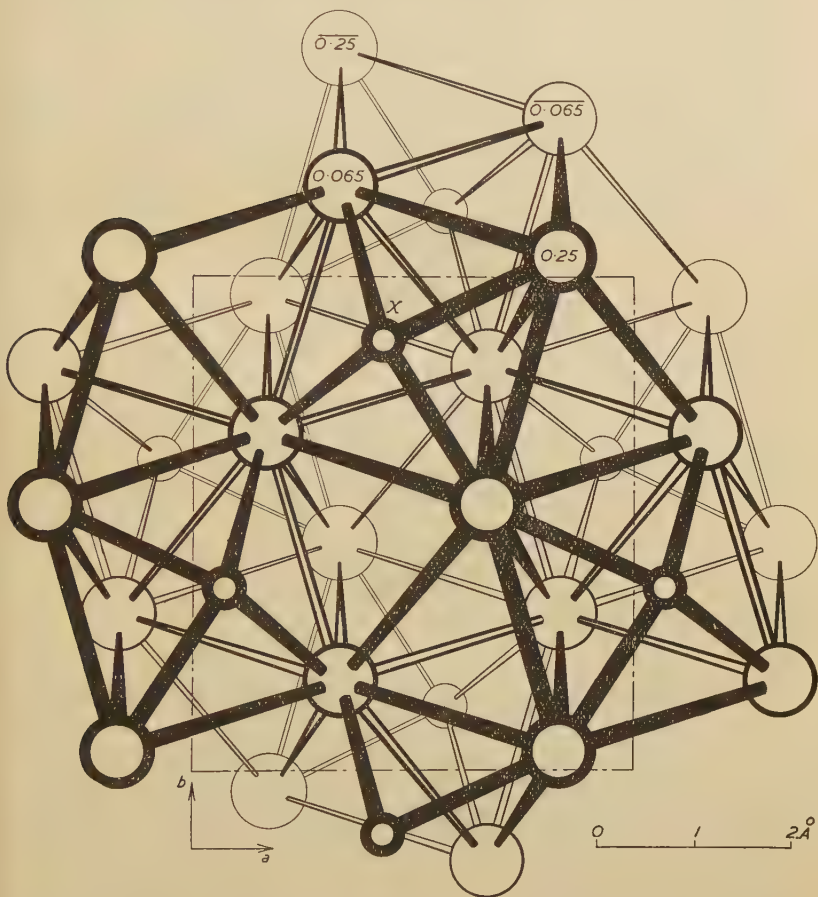
FIG. 3.—Diagram of that Part of the Structure between the Planes $z = \frac{1}{4}$ and $z = -\frac{1}{4}$. The larger circles represent iron atoms, the smaller ones carbon, and the bolder outlines indicate the higher levels, as shown by the parameters of the four atoms near the top of the diagram.

nearly close-packed is evidenced by the fact that the iron atoms on the mirror planes have twelve neighbours, at distances 2·52 (2), 2·54 (2), 2·65 (2), 2·67 (2) and 2·68 Å. (4), while those in the general

positions have eleven, at distances 2·49, 2·51 (2), 2·52, 2·54, 2·55,
2·62 (2), 2·67 and 2·68 Å. (2). These distances are shown as con-
necting lines between the atoms in Fig. 3, which represents that
part of the structure which lies between the mirror planes at $z = \frac{1}{4}$
and $z = -\frac{1}{4}$. All the bonds are shown except those which are
vertically downwards ; there is one of these to each general iron
atom, and it connects it to the other atom which faces it across the
mirror plane.

The relation of the structure to either the α (ferrite) or γ (austenite)
structures is not very obvious. The numbers of neighbours for the
iron atoms approach more nearly to those in the γ structure (12)
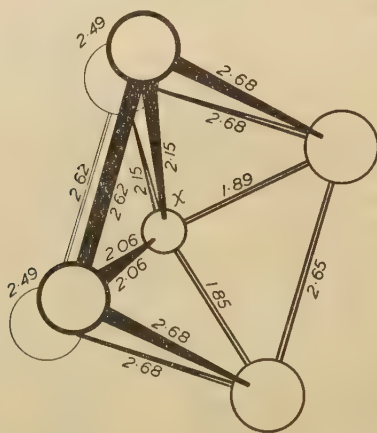
FIG. 4.—Environment of the Carbon Atom marked X in Fig. 3.   Interatomic
distances shown in Ångstrom units.

than in the α (8). The γ structure is cubic close-packed, which may
be regarded as consisting of a series of planes of close-packed atoms.
There are, of course, many ways of describing the structure other than
this, and the next simplest is in terms of planes of atoms arranged
at the corners of squares. Though these planes are less dense, they
fit more closely together. Now, the most densely packed planes
in the cementite structure are the (103) set, which, it will be seen
from Table I., has by far the largest structure amplitude. It is
found that these planes contain atoms arranged partly in the close-
packed triangular formation and partly in the square formation.
In this way there may be said to be a relation to the austenitic iron
structure, but too much stress cannot be placed on the similarity.

In austenite the carbon atoms almost certainly lie at the centres
of octahedra of iron atoms. The positions of the carbon atoms

in cementite suggested by Hendricks lie also in octahedra, but the true positions are actually distributed around these octahedra. The environment of the carbon atoms, as was first pointed out by Westgren, consists of six iron atoms arranged at the corners of a triangular prism.   These prisms cannot be seen in Fig. 3, as the carbon atoms lie in the top and bottom planes of the drawing. A prism is thus shown in Fig. 4, with an orientation corresponding to that round the atom marked X in Fig. 3, except that the two upper atoms have been slightly displaced.   Interatomic distances are also shown in this figure, and it will be noted that the average Fe–C distance is 2·03 Å.   This figure will have more significance than any of the separate values.   There are, however, two more iron atoms which are distant only 2·31 Å. from each carbon, and it is quite possible that these atoms should be taken into account when discussing the environments of the carbon atoms.

Acknowledgments.

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(7) BRAGG and WEST : *Philosophical Magazine*, 1930, vol. 10, p. 823.
(8) "Internationale Tabellen zur Bestimmung von Kristallstrukturen," Vol. 2.   Berlin, 1935.
(9) BRADLEY and HOPE : *Proceedings of the Royal Society*, 1932, A, vol. 136, p. 272.

CORRESPONDENCE.

Mr. H. A. SCHWARTZ (Cleveland, Ohio, U.S.A.) wrote that the authors' work seemed to have given confirmation of the cementite structure first suggested by Westgren. The fact that the structure so decided upon was not so well related to that of austenite as was the structure of cementite proposed by Hendricks should probably not be given too much weight in opposition to the present structure.

The greatest uncertainty in the present work might be the question whether a material prepared by the simultaneous reduction and carburisation of iron oxide was actually cementite. One needed to remember only that cementite accidentally contaminated with oxygen had been found by McCance, by Matsubara and by Schenck to be stable towards iron and carbon in order to realise that the presence of even small amounts of oxygen did something quite important to cementite—whether this something was related to the crystal structure was apparently entirely unknown.

The instability of the present authors' materials at annealing temperatures suggested that Taylor succeeded in completely removing the oxygen. In work of such a fundamentally important nature as the present, it might be well to have on record more definite confirmation of the extreme purity of the materials worked on. One found no statements of any kind on this subject.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), wrote that he had read the paper with much interest. The method appeared to be a reasonable one for establishing the position of the carbon atoms, but one was not in a position to criticise the method.

The actual distribution of the iron atoms bore no clear relation to that of either the body-centred or the face-centred cubic lattices. One aspect appeared to give a nearly perfect hexagonal lattice, so that it might be taken that the distribution of the iron atoms in cementite was more nearly that of γ-iron than of α-iron. It was possible that this might explain why cementite was more soluble in γ-iron than in α-iron.

Dr. A. H. JAY (Stocksbridge, near Sheffield) wrote to congratulate the authors on the success achieved in the determination of the atomic structure of cementite.

He would like to thank Dr. Lipson for having supplied him with the details of their X-ray powder photograph and, believing that this information—sin θ, intensity values—would be welcomed by other industrial X-ray workers, would suggest that the authors insert a short list of the inside lines in their reply.

Dr. S. A. MAIN (Sheffield) wrote that he had looked forward to this paper, forecast by Professor Bragg at the Institute's May

Meeting.   Knowledge of the structure of cementite had always seemed to him important, more specially in solving the problem of how austenite broke down into cementite and ferrite, either as pearlite or otherwise.   This took place with such facility and rapidity in carbon steel under suitable conditions that it would seem that the structures of these three constituents must be so nearly related that the manœuvre by which it was brought about must be an easy and orderly transition, somewhat of the character of a drill movement among the atoms.

In the much simpler case of iron changing its structure at Ar$_3$ from the face-centred structure of four interlacing cubic lattices to the body-centred of only two interlacing cubic lattices, some attempt could be made to visualise the mechanism of the movement.   The reason also for this re-formation in providing more open spacing of the atoms—reduced to uncomfortable crowding by thermal contraction—could also be clearly grasped.

Unfortunately, in the present case the structure of cementite now disclosed was apparently so intricate that, as one gathered from p. 102 P, such skilled crystallographers even as the authors could not readily see their way to establish the connection between it and the structures of austenite and ferrite, or, therefore, the nature of the manœuvre referred to.

It would be helpful, too, if the authors could say whether there was anything in the structure of cementite to make it unstable at or about 700° C. (Ac$_1$ or Ar$_1$)—in other words, unstable in such a way as to make its constituents carbon and iron, on heating, seek more comfortable bonds with the surrounding iron, or *vice versa*, namely, on cooling, to make them dissolve their bonds with the iron in austenite so as to form a more stable combination as cementite.

Nevertheless, it was an important step in this direction to have established the true structure of cementite, which was a first necessity in any understanding of these changes which were of so much consequence to the properties of steel.

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AUTHORS' REPLY.

The AUTHORS replied that Mr. Schwartz questioned whether the material used was actually cementite.   The authors, however, considered that there was no doubt about this, since all the lines on the X-ray photograph could be indexed on the basis of Westgren's measurements of the unit cell.   The material was not accurately analysed and no information was available about its oxygen content, but it was considered unlikely that the presence of small amounts of other elements could alter the structure fundamentally. The authors were more concerned about Mr. Schwartz's opening sentence, which would imply that there was still some doubt concerning the carbon positions in cementite.   They felt quite con-

fident that their work had given a positive answer in favour of Westgren's structure and had disposed completely of Hendricks'.

The authors agreed with Dr. Hatfield and Dr. Main on the difficulty of interpreting the structure. Any properties of the structure must be merely tentative until some method could be found for calculating free energies, but, unfortunately, this could not be done for even the simplest structures. The question of the stability of cementite raised by Dr. Main was not one which, even so, could be solved from the structure alone; a structure became unstable, not necessarily owing to its own properties, but because other atomic arrangements achieved a lower free energy.[1] Thus, to answer Dr. Main's question it would be necessary to be able to calculate the variation with temperature of the free energies of all the phases involved in the formation of cementite, an obvious impossibility in the present state of knowledge.

TABLE A.—*Observed Positions and Intensities of Lines in the X-Ray Pattern of Cementite, Fe_3C, taken with Co K_a Radiation.*

Sin θ.	Intensity.	Indices.	Sin θ.	Intensity.	Indices.
0·3445	1·0	0 2 0	0·4460	12·6	2 1 1
0·3681	14·4	1 1 2, 0 2 1	0·4718	7·2	1 1 3
0·3882	6·3	2 0 0	0·4772	9·2	1 2 2
0·3968	5·8	1 2 0	0·5015	3·8	2 1 2
0·4180	14·2	1 2 1	0·5255	3·8	0 0 4, 0 2 3
0·4258	15·6	2 1 0	0·5398	1·6	2 2 1
0·4343	14·2	0 2 2	0·5580	4·5	1 3 0
0·4381	23·2	1 0 3			

The authors were glad to have Dr. Jay's encouragement and to learn from him that the details of the cementite X-ray pattern were of interest to industrial workers. The information for which he asked was, of course, derivable from the Table in the paper, but was probably more useful in the form that he suggested. The Table was given in that form in Table A.

[1] H. Lipson and A. J. C. Wilson, " Some Properties of Alloy Equilibrium Diagrams Derived from the Principle of Lowest Free Energy," this Journal, p. 107 P.

SOME PROPERTIES OF ALLOY EQUILI-BRIUM DIAGRAMS DERIVED FROM THE PRINCIPLE OF LOWEST FREE ENERGY.*

By H. LIPSON, D.Sc., and A. J. C. WILSON, Ph.D. (Cavendish Laboratory, Cambridge).

Summary.

The purpose of this paper is to draw attention to the use of the principle of lowest free energy, as distinct from the phase rule, in the construction of equilibrium diagrams for binary and ternary alloy systems. Although free energies in themselves cannot be calculated, the principle leads to certain results which can be used to check experimental work. Though these results are quoted in the literature on the subject, several diagrams have been found which contravene them, and it would thus appear that they are still not generally appreciated.

The principle of lowest free energy was first introduced into the subject by Roozeboom, who used it to derive all the forms of binary equilibrium diagrams. Also, using purely thermodynamic reasoning, he produced many important theorems concerning ternary equilibrium diagrams. The present paper shows, first, that the free-energy principle can be used to produce further detail in binary systems, and, secondly, that by applying it to ternary systems Roozeboom's theorems may be derived much more simply than by his original methods.

Introduction.

THE second law of thermodynamics may be expressed in the form that, in any system in which the temperature and pressure are fixed, the thermodynamic potential, ϕ, must be a minimum :

$$\phi = U - TS + pV,$$

where U is the internal energy, T the absolute temperature, S the entropy, p the pressure and V the volume. In alloy systems pV is ordinarily small compared with $U - TS$, and may be neglected. Then the condition for equilibrium is that the free energy, F, where $F = U - TS$, should be a minimum.

For a pure metal F is a function of T only, and thus at a given temperature only one structure should exist. As the temperature increases, the free energy of this structure may decrease less rapidly than that of another structure, and at a certain temperature the two may become equal. At this temperature, and only at this temperature, can the two structures co-exist permanently, and above it the second structure will be the stable one.

In alloy systems the free energy is a function of composition

also. A given alloy may exist in more than one form, but its equilibrium state will be that form or mixture of forms for which the free energy is lowest. In a binary system, for instance, we may imagine the free energy for different structures plotted against composition, thus obtaining a number of curves. It can be shown that, since free energies are additive, the lowest free energy for any alloy must lie either on one of these curves or on one of the common tangents to them. This is illustrated in Fig. 1. The shapes and relative positions of the curves will alter with temperature, and by considering all possible types of changes Roozeboom [1] was able to deduce all the fundamental forms of phase diagrams for binary systems.

The same principles may be applied to ternary systems, but here the free-energy curves are replaced by surfaces, since compositions are represented by two variables. The state of lowest free energy for any composition is represented by either a point on a free-energy surface, a point between the points of contact of a plane tangent to two surfaces, or a point on a tangent plane common to three surfaces.

The information obtained in this way concerning the numbers of phases which can exist in equilibrium is such as could have been obtained from the phase rule, but it will be shown that further detail may be deduced which is not given by the phase rule.

A.—*Binary Systems*.

It will be necessary first to prove the validity of the construction mentioned above.[2] In Fig. 1 free energy is plotted against composition. Now, consider a composition represented by the line *PQ*,
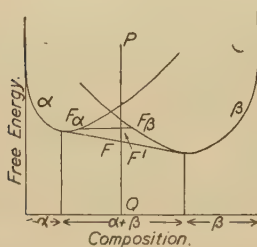
FIG. 1.—Relation between Free-Energy Curves and Phase Boundaries.
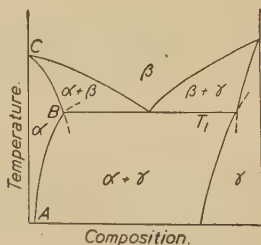
FIG. 2.—Possible (left) and Impossible (right) Relations between Phase Boundaries and Horizontals.

and that it may form the two structures of which the free-energy curves are marked α and β. The free energy of the β structure will be lower than that of the α structure, but a two-phase state may be found which has a lower free energy still. If, for instance, the alloy

splits into two phases of which the free energies are F_α and F_β, since free energies are additive, the resultant is given by the point F', which is the intersection of the lines PQ and $F_\alpha F_\beta$. It is obvious that the lowest position F' can have is F, which is on the common tangent to the two curves. Thus all alloys which lie between the compositions which are represented by the points of contact of this common tangent will have minimum free energy if they are in the two-phase state. To the left of this region the α structure will be stable, and to the right of it the β structure.

The correctness of this construction is generally assumed in the co-ordination of experimental results to produce phase diagrams, but in some cases the original derivation seems to have been lost sight of. A very important detail is the change in direction of a phase boundary at a point where it is touched by a temperature horizontal. An example of a binary phase diagram obeying the phase rule is shown in Fig. 2. The temperature, T_1, of the horizontal is that at which the free-energy curves for the α, β and γ structures have a common tangent. Below this temperature the curve for β lies wholly above the common tangent to the curves for α and γ; above it, the curve for β intersects this common tangent. This latter case is shown in Fig. 3, and it will be seen that the phase boundary of the α structure,
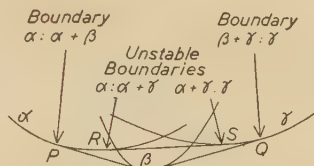
Fig. 3.—Relative Positions of Free-Energy Curves above the Eutectoid Temperature.

P, must lie to the left, and that of the γ structure, Q, to the right, of the phase boundaries, R, S, which would exist if the β structure were absent. The point P is representative of any point on the line BC in Fig. 2, and the point R is representative of any point on the line AB produced. Thus the line BC must lie wholly to the left of the line AB produced. In a similar way it may be shown that the line AB must lie wholly to the left of the line CB produced. In other words, the continuations of the phase boundaries must lie within the two-phase regions, as shown for the α-phase field in Fig. 2, and not in the single phase field itself, as shown for the γ-phase field.

This rule has been pointed out before, for example, by Vogel.[3] However, a critical examination of the phase diagrams collected by Hansen[4] shows ten diagrams, at least, which contain detail violating it. That these diagrams are mainly tentative merely stresses the importance of a general realisation of the restrictions on their forms on which theory insists.

As an example may be quoted the diagram proposed by Ishiwara[5] for the aluminium-manganese system. The part in question is shown in Fig. 4. It will be seen that the shape of the γ-phase boundary, where it is in equilibrium with α and with β, is incorrect, because the continuations of the boundaries both lie within the single-phase field.

Another interesting case occurs in the system cadmium-tin. Matuyama [6] proposed the diagram shown in Fig. 5 (a) to account for an arrest at 128° C.; it will be seen that the α-phase boundary has an impossible shape. It is interesting to note that the diagram, initially supported by the measurements of Hanson and Pell-Walpole, [7] was later revised by them [8] to the form shown in Fig. 5 (b), which does agree with theoretical principles. Incidentally, the free-energy principle could have been adduced to settle the argument between Gayler and Hanson [7] on the theoretical possibility of a diagram of the type shown in Fig. 5 (a).

The application of the free-energy principle to the positions of maxima in the liquidus of a system is also instructive. These maxima are usually indicative of the existence of inter-metallic compounds, and it is often taken that the position of a maximum
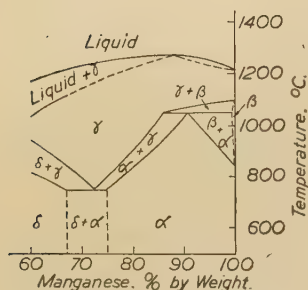
Fig. 4.—Part of the Aluminium-
Manganese System.
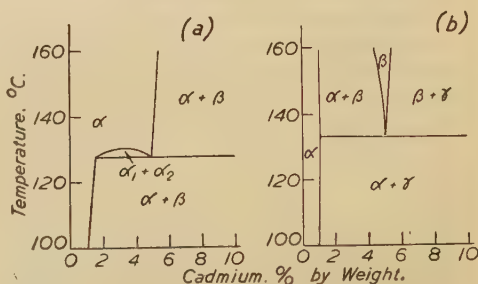
Fig. 5.—Part of the Cadmium-Tin System.
(a) Diagram proposed by Matuyama and initially supported by Hanson and Pell-Walpole. (b) Diagram revised by Hanson and Pell-Walpole.

gives accurately the formula of such a compound. This, however, is not necessarily true, since the position of the maximum is given by the temperature and composition at which the free-energy curve for the liquid touches that for the compound. Thus it must depend on the properties of both the curves, not on those of that for the solid alone. In the extreme case, when the curve for the solid has a sharp minimum, corresponding to a small homogeneity range, the maximum in the solidus must coincide with the composition of the compound fairly closely; but if the homogeneity range is wide this may not be so. Failure to realise this is evident in the work of Norbury, [9] who attempts to justify formulæ for various compounds on the basis of the positions of maxima in the liquidus.

The use of the free-energy principle leads to other results, which at first sight seem rather strange, but which are nevertheless in good accord with the results of experiment. For instance, Rush-

brooke [10] has pointed out that solubility limits have no connection with the position of the minimum of the free-energy curve, and may often lie both to one side of this minimum.   Consideration of Fig. 6 shows, indeed, that only one curve in any particular system can have its minimum between the limits of homogeneity.   If one makes the plausible assumption that the minimum is associated with the ideal stoichiometric composition, the frequent occurrence of phase fields which do not include this composition is readily explained.

B.—*Ternary Systems.*

I. *General.*

The usual method of representing the composition of a ternary alloy is by a point in an equilateral triangle.   For example, in Fig. 7, if the altitude of the triangle represents 100%, the point P represents
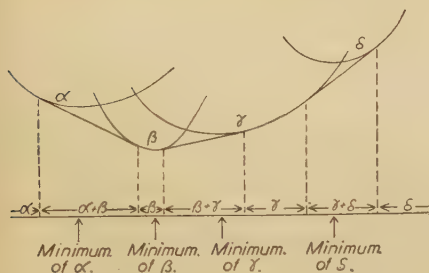
Fig. 6.—Relations between Free-Energy Minima and Homogeneity Ranges.
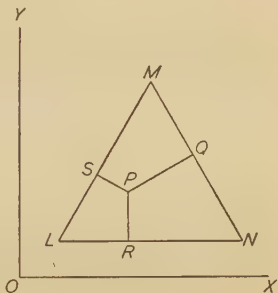
Fig. 7.—The Representation of Alloy Compositions in Ternary Equilibrium Diagrams.

an alloy of $PQ\%$ of the component L, $PR\%$ of M, $PS\%$ of N.   An alloy can in general exist in several different forms with different free energies.   Above each point in the triangle the free energy of each form of the alloy may be plotted as the z co-ordinate.   The result will be a series of surfaces.   Given a sufficiently long time the alloy will go into that form, or mixture of forms, which will make its free energy a minimum.   Perhaps the best physical picture of the process of finding the lowest free energy is to imagine a plane in contact with the surfaces and rolling over them.   As long as it is in contact with only one surface the alloy the composition of which is represented by the projection of the point of contact will be single-phase.   When it is rolling over two surfaces all alloys the composition of which lie on the projection of the line joining the points of contact will be a mixture of the two phases the compositions of which are the projections of the points of contact.   The projections of the *loci* of the points of contact are boundaries of the

single-phase regions and will in general be curved. When the plane comes into contact with three surfaces it cannot roll. Alloys the compositions of which fall within the triangle formed by joining the projections of the points of contact will be a mixture of the three phases represented by the corners. A plane cannot be in contact with more than three surfaces, except as a special case, and as the free-energy surfaces move relatively to one another with change in temperature, more than three phases will not co-exist over a range of temperature.

The intuitive use of this construction (and of the obvious fact that breaking up into more than one phase does not change the gross composition of the alloy) will lead to many of the properties of the equilibrium, but its correctness needs formal proof, and one or two of the theorems are not immediately obvious from it.   For
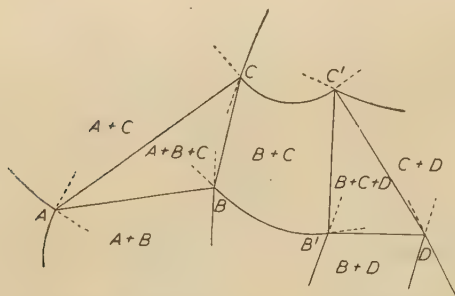
FIG. 8.—Possible (A, B, B') and Impossible (C, C', D) Corners of Three-Phase Triangles.
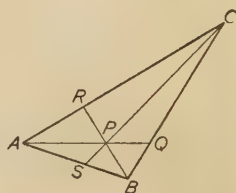
FIG. 9.—Construction for Finding the Proportions a, β, γ of the Three Phases A, B, C making up the Alloy of Composition P.

convenience the more important properties are listed here ; the proofs will be given in sections II. and III.

(a) *Properties of Two-Phase Fields.*—The points representing the alloy and the two phases which it forms lie on a straight line.   All alloys on this line form phases of the same composition.   The point representing the composition of the alloy divides the line inversely in the ratio of the relative amounts of the two phases.

(b) *Properties of Three-Phase Fields.*—The fields are triangles. The compositions of the phases are the same wherever within the triangle the alloy is situated, and are given by the corners of the triangle.   If the boundaries of the single-phase area touching a corner of the triangle be produced, both lie inside the triangle or one lies on each side of the triangle.   The angle between the produced boundaries on the side towards the triangle is less than 180°.   Thus

the corner may look like A, B or B' in Fig. 8, but it cannot look like C, C' or D.

If the relative amounts of the three phases A, B and C in Fig. 9 are α, β and γ, where $\alpha + \beta + \gamma = 1$, it may be shown (by solving equations 8 (a, b, c) below) that α is the area of the triangle PBC divided by the area of the triangle ABC, β is the area of the triangle PCA divided by the area of the triangle ABC, γ is the area of the triangle PAB divided by the area of the triangle ABC. It follows therefore that $\alpha = PQ/AQ$, $\beta = PR/BR$, $\gamma = PS/CS$ and that $\alpha/\beta = SB/SA$, $\beta/\gamma = QC/QB$, $\gamma/\alpha = RA/RC$.

The increase in entropy when atoms of three different kinds are mixed in an unordered homogeneous solid solution [11] leads to a term in the expression for the free energy :

$$- kT \log_e \frac{(A + B + C)!}{A!B!C!},$$

where A is the number of atoms of one kind, B of another and C of the third kind. This increases infinitely rapidly when A or B or C tends to zero, so a solid solution of sufficiently low concentration will have a lower free energy than a mixture in some phases of which one component is absent. It follows that a three-phase triangle will not ordinarily touch the border of the equilibrium diagram.

From this point the paper will consist chiefly of analytic geometry, so it will be convenient to describe the composition of an alloy by the rectangular co-ordinates (x,y) of the point P (Fig. 7) representing its composition.

II. *Two-Phase Fields.*

When an alloy of composition (x,y) breaks up into two phases of compositions (x_a,y_a) and (x_b,y_b) and relative amounts α and β, the conditions that the number of atoms of each kind remains constant are

$$
\begin{align}
x &= \alpha x_a + \beta x_b \quad . \quad . \quad . \quad . \quad . \quad . \quad (1a) \\
y &= \alpha y_a + \beta y_b \quad . \quad . \quad . \quad . \quad . \quad . \quad (1b) \\
1 &= \alpha + \beta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1c)
\end{align}
$$

Elimination of α and β leads to the equation

$$\frac{x - x_a}{x_b - x_a} = \frac{y - y_a}{y_b - y_a} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

i.e., (x_a,y_a), (x,y) and (x_b,y_b) lie on a straight line. If the free energies of the two phases are $A(x_a,y_a)$ and $B(x_b,y_b)$ the free energy of the mixture will be $F = \alpha A + \beta B$.

For equilibrium dF is zero for any small change in the variables, *i.e.*,

$$dF = 0 = A\,d\alpha + B\,d\beta + \alpha A_x dx_a + \alpha A_y dy_a + \beta B_x dx_b + \beta B_y dy_b \quad . \quad (3)$$

where $A_x = \partial A/\partial x$, $B_y = \partial B/\partial y$, &c. The differentials $d\alpha$, $d\beta$,

dx_a, &c., are not all independent, since α, β, x_a, &c., are connected by the conditions (1).   Since x and y are constants,

$$0 = x_a d\alpha + x_b d\beta + \alpha dx_a + \beta dx_b \quad . \quad . \quad . \quad . \quad . \quad (4)$$
$$0 = y_a d\alpha + y_b d\beta + \alpha dy_a + \beta dy_b \quad . \quad . \quad . \quad . \quad . \quad (5)$$
$$0 = d\alpha + d\beta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

These equations may be used to eliminate three of the differentials, say, $d\alpha$, dx_a, dy_a.   Multiply (4) by $-A_x$, (5) by $-A_y$, (6) by $-A + x_a A_x + y_a A_y$ and add to (3).   We have

$$0 = (B - A_x x_b - A_y y_b - A + A_x x_a + A_y y_a)d\beta + \beta(B_x - A_x)dx_b + \\ \beta(B_y - A_y)dy_b.$$

The remaining differentials are completely independent, so the coefficient of each must vanish, therefore

$$A_x = B_x \quad . \quad . \quad . \quad . \quad . \quad . \quad (7a)$$
$$A_y = B_y \quad . \quad . \quad . \quad . \quad . \quad . \quad (7b)$$
$$x_a A_x + y_a A_y - A = x_b B_x + y_b B_y - B \quad . \quad . \quad . \quad (7c)$$

Equations 1 (a, b, c) and 7 (a, b, c) completely determine x_a, y_a, x_b, y_b in terms of x and y.   Only equations (1) contain x and y, so that *all* values of x and y which satisfy them will lead to the same values of x_a, y_a, x_b, y_b, *i.e.*, all alloys the compositions of which lie on the line determined by equations (1) will break up into the same two phases.

Equations (7) are the conditions that the surfaces $z = A(x,y)$, $z = B(x,y)$ should have a common tangent plane.   The projections on the (x,y) plane of the *loci* of the points of tangency are boundaries of the two-phase region, for if (x,y) do not lie between (x_a,y_a) and (x_b,y_b) equations (1) will call for a negative amount of one phase— an obvious impossibility.   The tie lines are the projections of the lines joining the points of tangency.   They cannot intersect inside the two-phase region.   Their intersection would require that the tangent plane be simultaneously in contact with four points on the surfaces, which is ordinarily impossible, or that one of the surfaces be concave downwards instead of upwards, which could not lead to a true minimum of free energy.

III. *Three-Phase Triangles.*

When an alloy of composition (x,y) breaks up into three phases of compositions (x_a,y_a), (x_b,y_b), (x_c,y_c) in proportions α, β, γ with free energies A, B, C, then

$$x = \alpha x_a + \beta x_b + \gamma x_c \quad . \quad . \quad . \quad . \quad . \quad (8a)$$
$$y = \alpha y_a + \beta y_b + \gamma y_c \quad . \quad . \quad . \quad . \quad . \quad (8b)$$
$$1 = \alpha + \beta + \gamma \quad . \quad . \quad . \quad . \quad . \quad . \quad (8c)$$

and the free energy of the mixture is

$$F = \alpha A + \beta B + \gamma C. \quad . \quad . \quad . \quad . \quad . \quad (8d)$$

By an argument exactly similar to that used in section II. it may be shown that the conditions for minimum F are

$$A_x = B_x = C_x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9a)$$
$$A_y = B_y = C_y \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9b)$$
$$x_a A_x + y_a A_y - A = x_b B_x + y_b B_y - B = x_c C_x + y_c C_y - C \quad . \quad (9c)$$

Equations (9) are the conditions that the surfaces $z = A(x,y)$, $z = B(x,y)$, $z = C(x,y)$ should have a common tangent plane. They determine the plane completely, independently of (8), so the compositions of the phases of a three-phase alloy are independent of its composition. If the alloy lie outside the triangle formed by joining the points (x_a,y_a), (x_b,y_b), (x_c,y_c) it cannot be three-phase, as equations (8) would call for a negative amount of one phase.

It still remains to prove the theorem :

> At any corner of a three-phase triangle the boundaries of the single-phase region when produced lie both inside or one on each side of the three-phase triangle. The angle between the produced boundaries on the side toward the triangle is less than π.

In Fig. 10 P represents one corner of the three-phase triangle,

FIG. 10.—A Corner of a Three-Phase Triangle, showing the produced boundaries of the adjacent single-phase area.

FIG. 11.—As Fig. 10, but with co-ordinates chosen so that the x-axis bisects the angle RPQ.

SP the boundary between A and $A + B$, TP the boundary between A and $A + C$. The equation of the boundary SP would be obtained by eliminating x_b and y_b from equations (7), but all that is needed is the slope $m_{ab} = \partial y_a / \partial x_a$ at the point P. Let the corners of the triangle be (X_a, Y_a), (X_b, Y_b), (X_c, Y_c). Multiply equation 7(a) by X_b, 7(b) by Y_b and subtract 7(c) from their sum. Then

$$(X_b - x_a)A_x + (Y_b - y_a)A_y + A = (X_b - x_b)B_x + (Y_b - y_b)B_y + B.$$

Differentiate with respect to x_a and then let $x_a = X_a$, $y_a = Y_a$, $x_b = X_b$, $y_b = Y_b$:

$$(X_b - X_a)A_{xx} + (Y_b - Y_a)A_{yy}m_{ab} + (X_b - X_a)A_{xy}m_{ab} + (Y_b - Y_a)A_{xy} = 0,$$

$$m_{ab} = - \frac{(X_b - X_a)A_{xx} + (Y_b - Y_a)A_{xy}}{(X_b - X_a)A_{xy} + (Y_b - Y_a)A_{yy}}.$$

Similarly the slope of TP at the point P is

$$m_{ac} = - \frac{(X_c - X_a)A_{xx} + (Y_c - Y_a)A_{xy}}{(X_c - X_a)A_{xy} + (Y_c - Y_a)A_{yy}}.$$

It will be convenient now to make the point P the origin and have the x-axis bisect the angle RPQ.   Then

$$m_{ab} = - \frac{1 + mA_{xy}/A_{xx}}{A_{xy}/A_{xx} + mA_{yy}/A_{xx}}, \, m_{ac} = - \frac{1 - mA_{xy}/A_{xx}}{A_{xy}/A_{xx} - mA_{yy}/A_{xx}},$$

where $m = $ *the slope of PR = $-$ the slope of PQ* (Fig. 11).   Since the free-energy surfaces are concave upwards at the point of tangency, A_{xx} and A_{yy} are positive and $A_{xy}{}^2$ is less than $A_{xx}A_{yy}$.*   Let the ratio A_{yy}/A_{xx} be k^2, where k may have any positive value, and the ratio A_{xy}/A_{xx} be δk, where δ is between $+1$ and -1.   Then

$$m_{ab} = - (1 + m\delta k)/k(\delta + mk) \text{ and } m_{ac} = - (1 - m\delta k)/k(\delta - mk).$$

---

* A note on the physical meaning of these conditions may be helpful. That $A_{xx}A_{yy} - A_{xy}{}^2$ should be positive is the condition that at the point of tangency the surface should approximate to an ellipsoid.   If it were negative the surface would be a " saddle-back " and the point of tangency could not represent a stable phase.   If it were zero the " point " of tangency would be a line.   That A_{xx} and A_{yy} should be positive is the condition that the surface be concave upwards, not downwards.   If $A_{xx} = A_{yy}$ and $A_{xy} = 0$ the surface approximates to a sphere and PU, PV are perpendicular to PR, PQ, respectively.

Near the point of tangency the equation of the surface may be expanded in a double series thus :

$$z_s = A + A_x x + A_y y + (A_{xx}x^2 + 2A_{xy}xy + A_{yy}y^2)/2 + \ldots,$$

where A, A_x, A_y, &c., are constants equal to the value of these functions at the point of contact.   The equation of the tangent plane is

$$z_p = A + A_x x + A_y y,$$

so the difference in level between the surface and the plane is

$$h = z_s - z_p = (A_{xx}x^2 + 2A_{xy}xy + A_{yy}y^2)/2, \text{ approx.}$$

For the surface to be convex upwards h must be positive for any small values of x and y.   By putting $y = 0$ it is easy to see that A_{xx} is positive, and by putting $x = 0$ that A_{yy} is positive.   Perhaps the easiest method of seeing that $A_{xx}A_{yy} - A_{xy}{}^2$ is positive is to solve for y :

$$y = \frac{- A_{xy}x \pm \sqrt{A_{xy}{}^2x^2 - A_{yy}(A_{xx}x^2 - 2h)}}{A_{yy}}$$

$$= \frac{- A_{xy}x \pm \sqrt{2hA_{yy} - (A_{xx}A_{yy} - A_{xy}{}^2)x^2}}{A_{yy}}$$

For real values of y, h must be positive, so for negative values of h, y must be complex ; $- (A_{xx}A_{yy} - A_{xy}{}^2)x^2$ is then negative, so $A_{xx}A_{yy} - A_{xy}{}^2$ is positive.

Three cases, illustrated in Fig. 12, must be distinguished :

(1) mk greater than 1. $1/k$ is less than m. $|m_{ab}|$ and $|m_{ac}|$ are less than $1/k$ for all values of δ, so PU and PV lie inside the triangle for all values of δ.
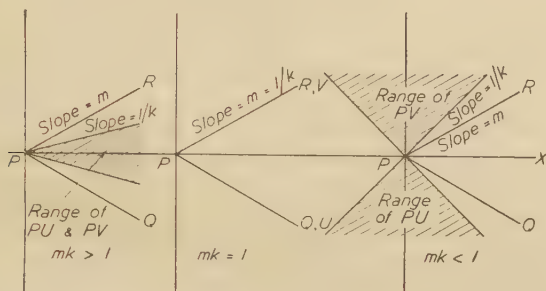
Fig. 12.—Ranges of Possible Positions of the Produced
Boundaries of the Single-Phase Area.

(2) mk equal to 1. PU coincides with PQ and PV with PR for all values of δ.

(3) mk less than 1. $1/k$ is greater than m. $|m_{ab}|$ and $|m_{ac}|$ are greater than $1/k$. PU and PV lie outside the triangle and on opposite sides of it for all values of δ.

The tangent of the angle VPU is given by

$$\frac{m_{ac} - m_{ab}}{1 + m_{ac}m_{ab}} = \frac{-(1 - m\delta k)/k(\delta - mk) + (1 + m\delta k)/k(\delta + mk)}{1 + (1 - m\delta k)(1 + m\delta k)/k^2(\delta - mk)(\delta + mk)}$$
$$= \frac{-2mk^2(1 - \delta^2)}{1 + \delta^2 k^2 - m^2\delta^2 k^2 - m^2 k^4}$$

This cannot change sign by passing through zero, so if the angle VPU be between 0 and π for any value of δ it must be between 0 and π for all values of δ.   It will easily be seen in particular cases (e.g., when $\delta = mk$ and PV is vertical) that the angle VPU is between 0 and π, and is therefore between these limits for all values of δ.

Acknowledgments.

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CORRESPONDENCE.

Dr. A. J. C. WILSON (Cambridge) wrote that, since this paper was written, he had been working out the geometrical rules govern- ing the form of four-component systems. The mathematical investigation had been communicated to the *Proceedings of the Cambridge Philosophical Society*, but a short account of the con- clusions might be of interest to The Iron and Steel Institute.

As was well known, the composition of a quaternary alloy could be represented by a point inside a tetrahedron. The four corners represented the pure components, and the fraction of each com- ponent was proportional to the perpendicular distance of the representative point from the face opposite the corner representing that component. The alloy might consist of a single phase, or of a mixture of two, three or four phases.

(1) A single-phase region was separated from two-phase regions by curved surfaces, met three-phase regions along ridges, and met four-phase regions in points where three ridges met.

(2) A two-phase region was separated from three-phase regions by ruled surfaces and met four-phase regions along straight lines. Through each point in a two-phase region there was a tie-line, with the properties given in sub-section I.(*a*) of the paper (p. 112 P).

(3) Three-phase regions were separated from four-phase regions by planes. Through every point in a three-phase region there was a plane, which might be called a " tie-plane," such that the alloy the composition of which was given by the point broke up into phases of which the compositions were given by the intersections of the plane with the ridges of the adjacent single-phase regions. All alloys with compositions lying on the plane broke up into the same three phases. The intersection of a tie-plane with the boun- daries of the adjacent two-phase regions was a triangle with its corners on the ridges of single-phase regions. If the intersections of a tie-plane with the surfaces bounding an adjacent single-phase region were produced towards the triangle, both lay inside the triangle or one lay on each side of the triangle. Tie-planes could not intersect inside the three-phase region. These rules were analogous to those of sub-section I.(*b*) of the paper (p. 112 P).

(4) Four-phase alloys were contained within tetrahedra. The compositions of the four phases were given by the corners of the tetrahedron, and were independent of the gross composition of the alloy. If the three ridges of a single-phase region meeting at a corner of the tetrahedron were produced towards the tetrahedron, three, one or none, but not two, might enter the tetrahedron.

(5) Three-dimensional models were clumsy to construct, so it would be convenient to use plane sections. Unfortunately, it was impossible to translate all the rules governing the three-dimensional model into rules governing sections. If, however, in such a section

a three-phase and a single-phase region touched, the single-phase boundaries when produced both entered, or one lay on each side of, the three-phase region. When a two-phase and a four-phase region touched, the boundaries of the two-phase region would ordinarily obey the same rule, but there might be exceptions when the section did not pass close to a corner of the four-phase tetra-hedron. In an arbitrary section there was no reason for a three-phase region to be triangular, but a four-phase region would be either triangular or quadrilateral.

Dr. C. H. DESCH, F.R.S. (Vice-President, London), wrote that in the course of the discussion at the Spring Meeting on the paper by Professor Bragg and his colleagues,[1] the present writer expressed the hope that Professor Bragg would prepare a short account of the free-energy concept as applied to alloys, showing the practical use which could be made of that concept. This paper by Lipson and Wilson admirably responded to this request. The authors had given certain very simple rules, deduced in an elementary way from considerations of energy, for deciding whether the boundaries between phase fields, arrived at by experiment, were possible or impossible. It was evident that many published diagrams included impossible boundaries, and a reconsideration of the experimental data, bearing in mind the rules now laid down, would lead to the drawing of more satisfactory diagrams. It was to be hoped that these considerations would be borne in mind by investigators and included in future text-book descriptions of metallographic methods. No advanced theory was involved, and it was satisfactory to find that the geometry was comparatively simple.

Dr. A. L. NORBURY (Research Department, Woolwich) wrote that the question raised by the authors of whether a maximum on the liquidus did, or did not, precisely indicate the ideal composition of an intermetallic compound was one of considerable importance in theoretical metallurgy. A considerable number of cases were known of intermetallic compounds the maxima of which were precisely at the ideal composition. He submitted that no case was known of an intermetallic compound of definitely established com-position with a liquidus maximum at a different composition.

The idea that this sometimes happened might have arisen from the consideration of phases having a γ-brass structure, the maxima of which did not occur at the 21-electron/13-atom ratio originally assumed for these structures.

In the paper referred to by the authors,[2] he (the writer) had shown that the maxima in these phases occurred at compositions having an electron/atom ratio of 83/52, instead of the 21/13 ratio

[1] *Journal of the Iron and Steel Institute*, 1940, No. I., p. 63P.
[2] A. L. Norbury, *Journal of the Institute of Metals*, 1935, vol. 65, p. 355.

previously assumed. The 83/52 ratio for these phases was deduced from another line of reasoning and was supported by other evidence.

Dr. A. H. JAY (Stocksbridge, near Sheffield) wrote that he was extremely interested in this paper and desired to put a number of questions to the authors.

On the first page it was stated that the product pV was ordinarily small compared with $(U - TS)$. Would the authors give dimensions and quantities to these symbols in support of this statement ? It seemed to the writer that p, at least, could be very large during certain phase changes, especially those which took place at low temperatures, though in these cases it might be reasoned that the simplified equation referred only to equilibrium conditions, where presumably stresses were at a minimum, there being a continuous annealing or stress-relieving process during any temperature change.

The last complete sentence on the second page was in itself misleading, for by the construction of Fig. 2 the free energy of a two-phase state was lower than that of, say, the α, but higher than that of the β phase—α and β both referring to the point of contact with the common tangent. The explanation was, however, made clear on the third page.

It was stated in the summary that free energies in themselves could not be calculated, and therefore in respect to Figs. 3 and 6 he wished to make the following comments : It would appear that, in regard to Fig. 3, the disposition of the individual α, β and γ curves was based on the experimental facts of phase regions. Thus, for temperatures above T_1 the β curve was positioned so as to cut the line PQ to a degree consistent with the solubility curves above T_1 in the equilibrium diagram. Below temperature T_1 the β free-energy curve, which was now really above the line PQ, would allow of an inverted V, thus $\mathsf{\Lambda}$, but because of the operation of minimum-free-energy conditions the new state was given by the line PQ joining α to γ; in other words, β did not here exist and an inflection could not arise in the free-energy curve for equilibrium conditions. On this point, would supercooling or a partially suppressed change be represented by an inflection, thus giving a W-shaped curve ?

One last point—did the statement regarding Fig. 6 (*see* p. 111 P, first paragraph), that there was only one curve with its minimum between the limits of homogeneity, preclude the possibility that at another temperature another curve could provide this property ?

It was clear that this paper would be of great value to those engaged in the determination of alloy phase boundaries under equilibrium conditions.

AUTHORS' REPLY.

The AUTHORS were glad that Dr. Desch considered that their paper filled satisfactorily the need for a simple exposition of the principle of lowest free energy.

The point raised with regard to Dr. Norbury's work was not that his formulæ were incorrect, but that the position of the maximum in the liquidus was not evidence of their correctness. His theory of the replacement of atoms by electrons must be judged on other grounds. The crystal structure of γ-brass established Cu_5Zn_8 as its "ideal" composition, but the point made in the paper was that it need not have its ideal composition exactly, either at its melting point or elsewhere.

As Dr. Jay suggested, the simplified formula $F = U - TS$ was intended to apply only to the equilibrium state, in which p was equal to the vapour-pressure of the alloy and was negligibly small. However, $U - TS$ was of the order of $-3RT$ per g.-atom for temperatures of interest in metallurgy. At 500° C. this was $-4,600$ cal. per g.-atom, or about -2×10^5 c.c.-atm. per g.-atom. As the volume of a gramme-atom of metal was about 10 c.c., pressures of about 10,000 atm. were required to make pV of the same order as $U - TS$.

In the last sentence of the second page the free energies referred to were the points at which PQ intersected the free-energy curves, not the points of tangency. It was regretted that the statement was not sufficiently full to make this clear.

The authors did not fully understand Dr. Jay's third question. However, none of the considerations advanced in the paper applied to non-equilibrium states. The statement that only one free-energy curve could have its minimum within the limits of homogeneity ought to have been qualified by adding " at any given temperature."

THE DECOMPOSITION OF PEARLITE IN GREY CAST IRON.*

By A. A. TIMMINS, A.I.C. (British Cast Iron Research Association, Birmingham).

(Figs. 12 to 24 = Plates III. to VI.)

Synopsis.

A study was made of some of the conditions governing the decomposition of pearlite in grey cast iron. For this purpose three irons, differing only in silicon content, were heated at constant temperatures for various periods of time. Sections of the corresponding bars in the annealed condition were also similarly heated. Data were obtained which confirm the assumption that the removal of pearlite on annealing at constant temperature depends on the diffusion of carbon through the iron. The results show that combined carbon can be removed quite readily by annealing at temperatures below the critical point of the iron, the rate of removal being more rapid, the nearer the heating temperature is to the critical point. It is also shown that heating at temperatures above the critical point may or may not remove combined carbon, depending on whether or not the combined-carbon content is above or below the equilibrium percentage. When heating at these temperatures the rate of cooling is the major factor in the removal of pearlite, whilst the duration of the soaking is the most important point to be considered when heating at temperatures below the critical point.

The results obtained have a bearing on the softening of cast iron to give easy machinability, and show that the most satisfactory temperature for annealing purposes is one near the critical point.

It has been known for some considerable time that grey cast iron undergoes a change in its structure on heating at high temperatures and that this change is due to the breakdown of the combined carbon. The phenomenon of " growth " has done much to promote the study of the conditions governing this decomposition. With the advent of the heat treatment of cast iron, an exact knowledge of the mechanism of pearlite decomposition has become more desirable.

However, the most extensive work in this direction has arisen in the study of malleablisation processes in the production of malleable cast iron. Much pioneer work has been conducted on the breakdown of free cementite in malleable cast iron by Schwartz [1] and his collaborators. He and also White and Schneidewind [2] have put forward the suggestion that malleablisation is brought about by the formation of nuclei in the iron which act as centres for the precipitation of temper carbon. When these nuclei are

formed, these workers suggest, the carbon in solution in the austenite migrates towards them, and is deposited there as free carbon. This migration continues until the equilibrium carbon content for that particular heating temperature is reached.

This idea is supported by the fact that curves relating to the graphitisation rate of free cementite are similar to those of well-known diffusion phenomena. Ishiwara [3] has also shown that the diffusion velocity of carbon in iron is a logarithmic function of the temperature and follows a curve similar to that of the relationship between the graphitisation rate and temperature.

Kikuta [4] has demonstrated that the rate of breakdown of cementite in white iron is increased with an increase in the silicon and carbon content.

Thus, so far as malleable cast iron is concerned, malleablisation depends on :

(1) The mobility of carbon in austenite.
(2) The tendency to form nuclei.

The variability of this latter point often obscures the true nature of the changes. Thus, fine-grained white irons are found to malleablise more easily than coarse-grained irons of the same analysis.

Kikuta and, later, White and Schneidewind have also shown that the removal of pearlite by heating at temperatures below the critical point (second-stage graphitisation of malleable cast iron) may also be explained by the same reasoning, the latter authors suggesting that the carbon goes into unstable solution in α-iron and then migrates to the graphite nuclei, where it is deposited.

So far as grey iron is concerned, it is probable that no nuclei are formed, these being provided by the large number of graphite flakes already present.

Whilst a study of graphitisation rates is probably more important from the point of view of malleable cast iron, it is also of great interest to the grey-iron industry. With the advent of modern mass-production methods, resort must be had to annealing in order to obtain the high machining speeds required. Whilst it is known that cast iron can be softened by annealing, the exact procedure to be adopted is not often understood. The question of annealing is also of importance from the point of view of stress removal. This is a treatment sometimes carried out at temperatures near the critical point and has for its object the removal of stresses imposed during the cooling of the casting in the mould. As the pearlite is the main factor so far as strength is concerned, it is obviously important to use a temperature which will not destroy the pearlite and so weaken the casting.

An investigation was conducted with a view to determining the conditions governing the decomposition of pearlite in grey cast

iron. For this purpose two irons of similar composition except for the silicon content were obtained in the form of 1·2-in. dia. bars. The analyses of the bars were as follows :

	Iron A.	Iron B.
Total carbon	2·96%	3·09%
Combined carbon	0·70%	0·56%
Graphitic carbon	2·26%	2·53%
Silicon	1·85%	2·42%
Manganese	0·56%	0·73%
Sulphur	0·03%	0·03%
Phosphorus	0·18%	0·23%
Chromium	0·12%	0·13%

Sections of $\frac{1}{2}$-in. thickness were cut from the bars and heated in a small electrically-heated tube furnace. The temperatures chosen were 700° C. and 900° C., so that the conditions governing the annealing could be studied at temperatures above and below the critical point of the iron used. The sections were placed in the furnace when at the desired temperature, and heated for $\frac{1}{2}$ hr. or $2\frac{1}{2}$ hr., after which they were withdrawn from the furnace and cooled in air. Other specimens were heated for the same periods at the same temperatures, but cooled at different rates, namely " slow cooling," approximately 3° C. per min., and " very slow cooling," approximately 1° C. per min. The critical points for the two irons were determined as follows :

	Ac Point.	Ar Point.
Iron A	776° C.	721° C.
Iron B	792° C.	737° C.

Microscopic examination and combined-carbon determinations were conducted on the heat-treated samples in order to follow the changes which occurred. The combined-carbon determinations

TABLE I.—*Combined-Carbon Contents of the Two Irons after Various Treatments.*

Iron.	Soaking Period.	Air-Cooled.	Slow Cooling.	Very Slow Cooling.	As-Cast.
Soaking Temperature 700° C.					
A	$\frac{1}{2}$ hr. $2\frac{1}{2}$,,	0·56% 0·32%	0·56% 0·23%	0·53% 0·29%	0·70%
B	$\frac{1}{2}$ hr. $2\frac{1}{2}$,,	0·49% 0·18%	0·51% 0·19%	0·53% 0·16%	0·56%
Soaking Temperature 900° C.					
A	$\frac{1}{2}$ hr. $2\frac{1}{2}$,,	0·80% 0·90%	0·78% 0·75%	0·65% 0·58%	0·70%
B	$\frac{1}{2}$ hr. $2\frac{1}{2}$,,	0·76% 0·81%	0·71% 0·66%	0·52% 0·41%	0·56%

were obtained by difference, following the estimation of the total-carbon and graphite contents by combustion.   The results obtained for combined carbon are given in Table I.

Examination of these figures shows that the combined-carbon content tends to decrease with an increase in soaking time at 700° C., but increases with an extension of the annealing period at 900° C. Considering the specimens annealed for the 2½-hr. period, it would appear that the subsequent rate of cooling is without effect on the
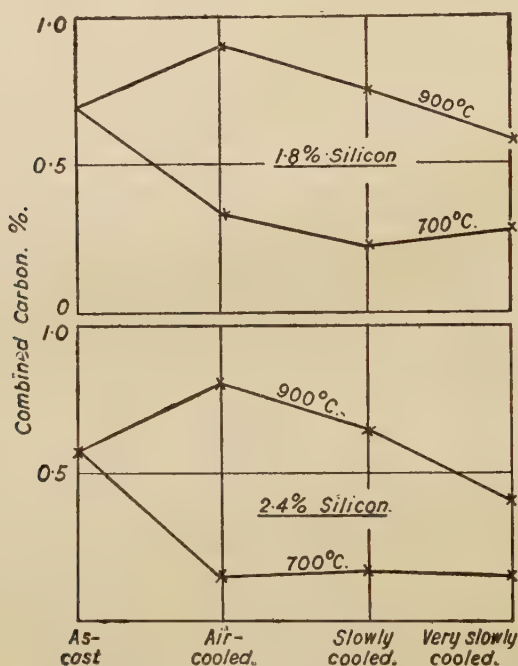
FIG. 1.—Effect of Rate of Cooling after Annealing.

removal of combined carbon when the heating temperature is 700° C., but for an annealing temperature of 900° C. a decrease in the subsequent rate of cooling brings about a drop in the combined-carbon content.   This is shown graphically in Fig. 1.   Fig. 2 shows the variation in Brinell hardness for the same specimens, and confirms the above findings.   Microscopic examination gave additional confirmation.   Figs. 12 to 19 illustrate the structures of the slowly-cooled specimens after heating for ½ hr. and 2½ hr. at 700 and 900° C.

Very little difference was detected between the microstructures of the as-cast bar A and the corresponding bar after annealing at

700° C. for $\frac{1}{2}$ hr. followed by slow cooling.   The specimen annealed for $2\frac{1}{2}$ hr. at 700° C., however, had an almost entirely ferritic matrix, with small amounts of coalesced pearlite round the phosphide eutectic.

Specimens from the same bar heated at 900° C. for $\frac{1}{2}$ hr. contained a completely pearlitic matrix, but the pearlite was of a finer lamination than that of the as-cast bar.   Annealing at 900° C. for $2\frac{1}{2}$ hr. produced only a little ferrite round the graphite flakes, the pearlite still being very fine.

Somewhat similar changes were noticeable in the specimens from bar B, but in this case a fair amount of ferrite was present in the bar annealed at 700° C. for $\frac{1}{2}$ hr.   The remaining pearlite
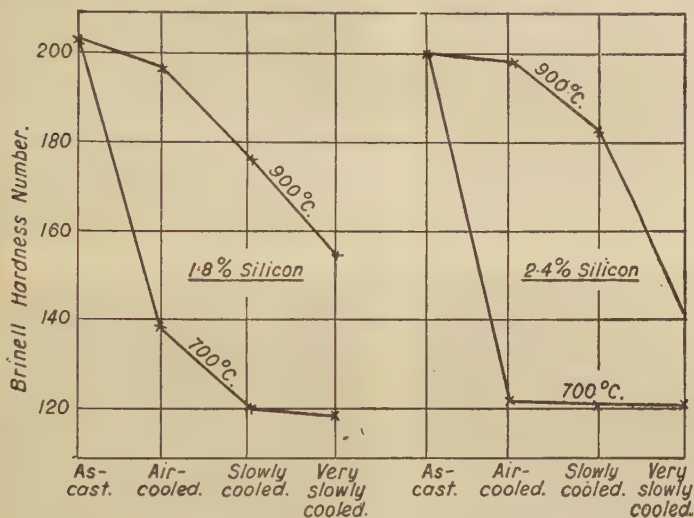
Fig. 2.—Effect of Rate of Cooling on Brinell Hardness.

was in a coalesced form and concentrated round the phosphide eutectic.   Annealing for the longer period of $2\frac{1}{2}$ hr. at 700° C. was sufficient to remove all but traces of the pearlite.

Those specimens annealed at 900° C. again showed a finely laminated pearlite with a steel-like appearance.   Small amounts of ferrite were present near the graphite in the sample annealed for $\frac{1}{2}$ hr. and larger amounts in those annealed for $2\frac{1}{2}$ hr.

Very little difference in the character of the microstructure was noticed in the bars after $2\frac{1}{2}$ hr. anneal at 700° C. followed by the different cooling rates.   In all cases, the structures were similar to those illustrated in Figs. 13 and 17.

From these results, it is apparent that for temperatures below the critical point, the time occupied at the soaking temperature is of the greatest importance in removing pearlite.   Half an hour was

considered to be more than sufficient time at 700° C. and 900° C. for the whole of the ½-in. section to be uniformly heated, and this surmise was substantiated by the uniformity of the structures of the bars.

Comparing Figs. 12 and 13, and 16 and 17, illustrating the structures of bars heated at 700° C., it would appear that the increase in silicon content facilitates the removal of pearlite.

When the annealing is carried out at a temperature above the critical point, a different condition arises. In this case, the time of soaking plays little part in the removal of the pearlite; in fact, a longer time may tend to increase the combined-carbon content. The rate of cooling after soaking is of major importance, the slower the rate of cooling, the greater being the amount of pearlite which is decomposed.

Following this preliminary work, an attempt was made to study in more detail the rate of formation and decomposition of combined carbon in grey cast iron. For this purpose, three irons of the following compositions were obtained in the form of 1·2-in. dia. bars :

	T.C. %.	C.C. %.	G.C. %.	Si. %.	Mn. %.	S. %.	P. %.
Iron 1	3·30	0·79	2·51	3·25	0·80	0·069	1·12
Iron 2	3·45	0·83	2·62	2·20	0·71	0·054	1·10
Iron 3	3·40	0·87	2·53	1·30	0·72	0·050	1·10

The critical points for these irons were determined as follows :

	Ac Point.	Ar Point.
Iron 1	816° C.	765° C.
Iron 2	786° C.	731° C.
Iron 3	764° C.	708° C.

Half bars from each of these samples were annealed to remove as much of the combined carbon as possible. The treatment given consisted of a 2-hr. soaking at 850° C. followed by slow cooling. In this way three further sets of bars, designated 1A, 2A and 3A, were obtained, having the same composition to those given above, but with lower combined-carbon contents.

Sections ½ in. in thickness were then cut from each of the as-cast and annealed 1·2-in. dia. bars and used for the following experiments.

Two sections, one from the as-cast bar and the other from the corresponding annealed bar, were heated at a definite constant temperature. At the end of a given time the specimens were removed from the furnace and rapidly quenched in cold water. The furnace used was an electrically-heated tube furnace arranged in a vertical position and provided with a platinum/platinum-rhodium thermocouple for recording the temperatures. Two specimens only were heated at one time, these being held by a Nichrome-wire cradle in the centre of the furnace adjacent to the thermocouple hot junction. The specimens were placed in the furnace when it was at the desired temperature, and, judging from the fluctuation in temperature soon after this procedure, the

PLATE III.

Fig. 12.—Bar *A* heated ½ hr. at 700° C. Slowly cooled. × 200.
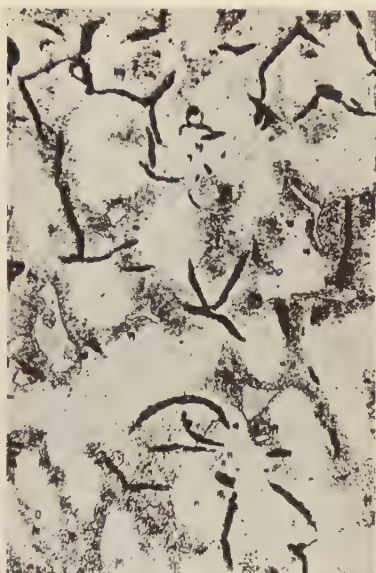
Fig. 13.—Bar *A* heated 2½ hr. at 700° C. Slowly cooled. × 200.
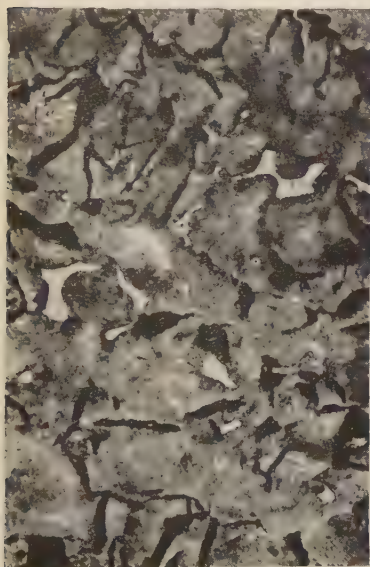
Fig. 14.—Bar *A* heated ½ hr. at 900° C. Slowly cooled. × 200,

Fig. 15.—Bar *A* heated 2½ hr. at 900° C. Slowly cooled. × 200.

[*Timmins*.
[*To face p.* 128 P.

PLATE IV.
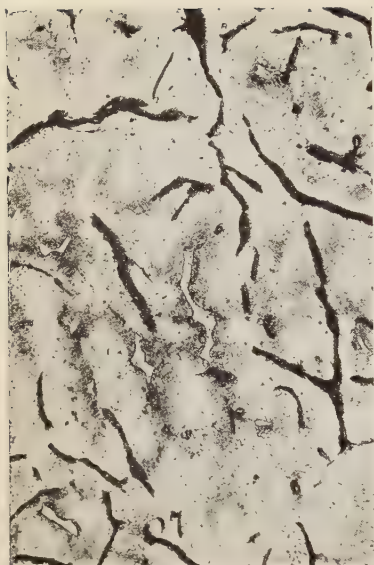
Fig. 16.—Bar *B* heated ½ hr. at 700° C. Slowly cooled. × 200.

Fig. 17.—Bar *B* heated 2½ hr. at 700° C. Slowly cooled. × 200.

Fig. 18.—Bar *B* heated ½ hr. at 900° C. Slowly cooled. × 200.

Fig. 19.—Bar *B* heated 2½ hr. at 900° C. Very slowly cooled. × 200.

[*Timmins.*

PLATE V.

FIG. 20.—Bar No. 2 heated $\frac{1}{2}$ hr. at 700° C. Quenched. × 300.

FIG. 21.—Bar No. 2 heated 1 hr. at 700° C. Quenched. × 300.

FIG. 22.—Bar No. 2 heated 3 hr. at 700° C. Quenched. × 300.

FIG. 23.—Bar No. 2 heated 6 hr. at 700° C. Quenched. × 300.

[*Timmins.*

PLATE VI.
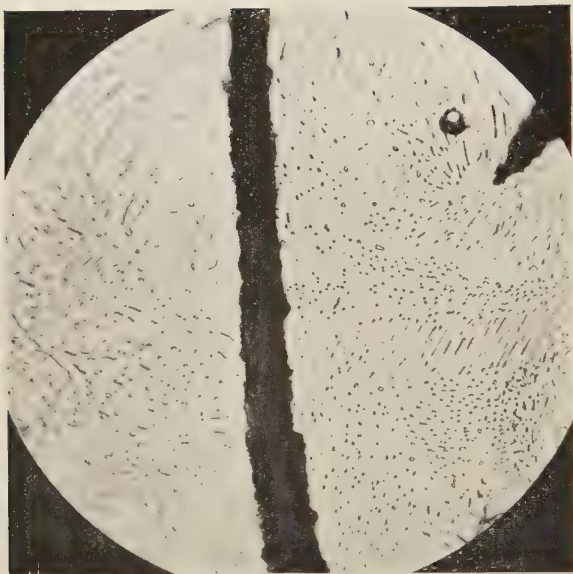
FIG. 24.—Bar No. 2 heated 4 hr. at 700° C.   Quenched.   × 1200.

specimens were considered to be completely heated through at the end of 5–10 min.   Temperature control was maintained to within $\pm$ 5° C.   At the end of $\frac{1}{2}$ hr., the cradle was dropped into a vat of water placed beneath the furnace.   Further specimens were similarly treated after different soaking times, and a series of samples was obtained which had been soaked at various temperatures for varying periods of time up to 8 hr.

Each specimen was then sampled for analysis and the total-carbon and graphitic-carbon contents were determined.   The total carbon was determined by the direct combustion method.   The graphite was obtained by dissolving a sample in 1·2 sp. gr. nitric acid and filtering through an asbestos pad.   After drying, the normal combustion method was employed, and the combined-carbon content was obtained by difference.   Owing to the variety of elements present in cast iron, the Eggertz colour method for combined carbon was not considered reliable.   It is also considered unsatisfactory for quenched specimens.

In the early stages of the work, considerable difficulty was experienced in the analysis, wide variations in combined carbon occurring between estimations on the same sample and on the same set of drillings.   Repeated runs of a standard carbon steel on the combustion furnace gave sufficient assurance that the combustion process was being performed correctly, and it was decided that the discrepancy was due to the following factors :

(1) Loss of graphite during the sampling.
(2) Incorrect proportioning of graphite and iron when weighing out samples for analysis.

Both these factors were aggravated by the relatively high proportion of graphite in some of the samples.

In order to reduce these difficulties, the following procedure was adopted.   The specimens were ground all over and then centred in a lathe chuck.   After turning off about $\frac{1}{8}$ in. from the face, turnings were taken with the aid of a round-nosed Widia-tipped tool, the specimen being rotated at a low speed.   By this means the turnings were obtained as " chips," which were collected on glazed paper.   A glazed-paper cowl was also used over the tool and specimen to collect any floating graphite, which, however, proved to be very slight.   Glazed paper was found to be more satisfactory than ordinary paper, as the graphite did not cling so tenaciously and could be easily brushed off on to the scale-pan on the balance. About 2–3 g. of turnings were obtained at one time and the whole of these were used for one estimation, of graphite or total carbon. Several sets of turnings were obtained from the face of each specimen and utilised for analysis.

When large amounts of sample were available, it was often found that fine particles containing a high proportion of graphite segregated

in the sample packet and tended to give variable results unless the correct proportion of fine and coarse particles was taken. By using the whole of the turnings for analysis, this was avoided. In addition, the turnings were not ground before being used, so as to reduce any loss of graphite during this operation.

The modifications adopted in sampling reduced the variation in the combined-carbon determinations. The figures given in Tables II. to IV. represent the mean of at least six determinations on each specimen.

The results are shown graphically in Figs. 3 to 9, where the combined-carbon content is plotted against the time of soaking at

TABLE II.—*Total, Graphitic and Combined-Carbon Contents of Bar* 1 *after Various Treatments.*

Time of Soaking. Hr.	As-Cast Sample.			Annealed Sample.		
	T.C. %.	G.C. %.	C.C. %.	T.C. %.	G.C. %.	C.C. %.
			Heated at 700° C.			
½	3·36	2·72	0·64	3·31	2·99	0·32
	...	2·66	0·70	...	...	...
1	3·32	2·78	0·54	3·30	3·02	0·28
1½	3·34	2·72	0·42	...	...	...
2	3·29	2·91	0·38	3·28	3·08	0·20
3	3·28	3·04	0·24	3·34	3·16	0·18
4	3·30	3·10	0·20	...	...	...
5	...	...	...	3·31	3·15	0·16
7	3·30	3·10	0·20	3·36	3·18	0·18
Initial	...	...	0·74	...	...	0·34
			Heated at 800° C.			
½	3·32	2·61	0·71	3·31	2·99	0·32
1	3·33	2·89	0·44	3·32	3·08	0·24
1½	3·34	3·04	0·30	...	...	...
2	3·28	3·06	0·22	3·29	3·08	0·21
3	3·30	3·10	0·20	3·33	3·13	0·20
4	3·29	3·11	0·18	3·35	3·17	0·18
5	3·31	3·10	0·21	3·37	3·17	0·20
Initial	...	...	0·74	...	...	0·30

Time of Soaking. Hr.	As-Cast Sample.		
	T.C. %.	G.C. %.	C.C. %.
	Heated at 900° C.		
½	3·32	2·59	0·73
1	3·34	2·62	0·72
2	3·28	2·64	0·64
3	3·29	2·71	0·58
5	3·31	2·69	0·62
Initial	...	...	0·74

TABLE III.—*Total, Graphic and Combined-Carbon Contents of Bar 2 after Various Treatments.*

Time of Soaking. Hr.	As-Cast Sample.			Annealed Sample.		
	T.C. %.	G.C. %.	C.C. %.	T.C %.	G.C. %.	C.C. %.
Heated at 700° C.						
½	3·42	2·60	0·82	3·46	3·18	0·28
1	3·43	2·73	0·70	3·40	3·20	0·20
1½	3·40	2·80	0·60	3·42	3·24	0·18
2	3·39	2·87	0·52	3·41	3·25	0·16
3	3·41	2·93	0·48	...	...	...
4	3·46	3·10	0·36	3·39	3·22	0·18
5	3·42	3·12	0·30	4·41	3·25	0·16
6	3·42	3·16	0·26	3·42	3·22	0·20
8	3·43	3·23	0·20	3·41	3·25	0·16
Initial	...	...	0·83	...	...	0·3

Time of Soaking. Hr.	As-Cast Sample.		
	T.C. %.	G.C. %.	C.C. %.
Heated at 770° C.			
½	3·42	2·62	0·80
1	3·40	2·80	0·60
1½	3·41	2·95	0·46
2	3·42	3·12	0·30
Initial	...	...	0·83

Time of Soaking. Hr.	As-Cast Sample.			Annealed Sample.		
	T.C. %.	G.C. %.	C.C. %.	T.C. %.	G.C. %.	C.C. %.
Heated at 800° C.						
½	3·45	2·69	0·76	3·42	3·27	0·15
1	3·42	2·82	0·60	3·41	3·13	0·28
1½	3·41	2·89	0·52	3·45	3·11	0·34
2	3·46	2·95	0·51	3·39	3·05	0·34
4	3·38	2·90	0·48	3·45	3·05	0·40
5	...	...	...	3·42	3·00	0·42
8	3·40	2·94	0·46	3·42	2·93	0·48
Initial	...	...	0·83	...	...	0·10
Heated at 900° C.						
½	3·39	2·71	0·78	3·40	2·76	0·64
1	3·41	2·67	0·74	3·46	2·81	0·65
1½	...	...	...	3·41	2·74	0·67
2	3·42	2·66	0·76	...	...	...
3	...	...	...	3·42	2·72	0·70
4	3·45	2·67	0·78	...	...	...
5	...	...	...	3·43	2·67	0·76
7	3·39	2·57	0·82	3·39	2·59	0·80
Initial	...	...	0·83	...	...	0·28
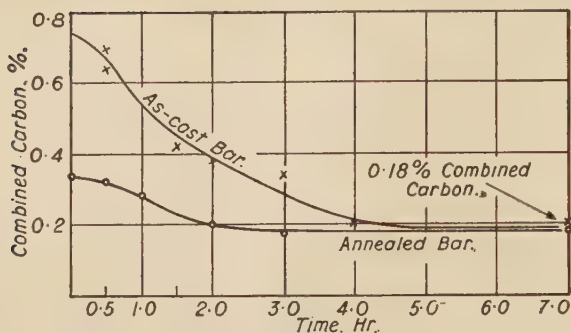
Fig. 3.—Bar No. 1 Heated at 700° C.
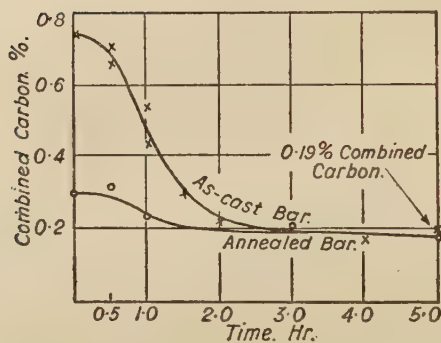
Fig. 4.—Bar No. 1 Heated at 800° C.
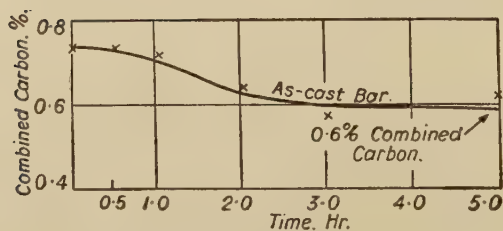
Fig. 5.—Bar No. 1 Heated at 900° C.
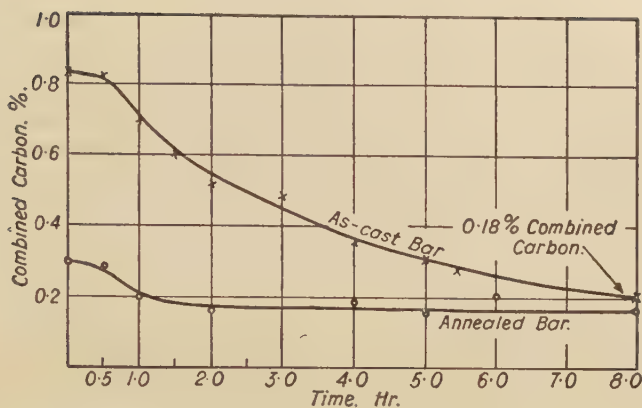
FIG. 6.—Bar No. 2 Heated at 700° C.
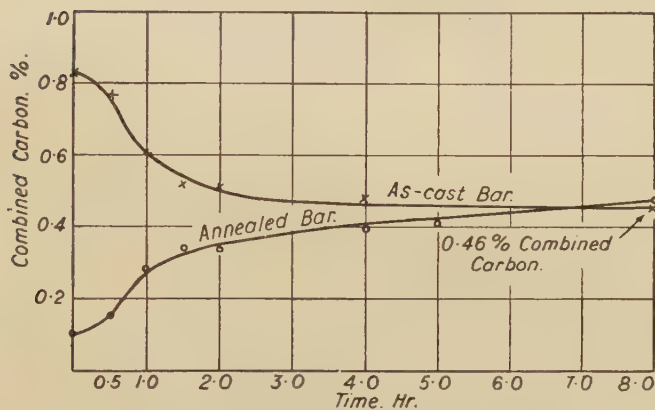
FIG. 7.—Bar No. 2 Heated at 800° C.
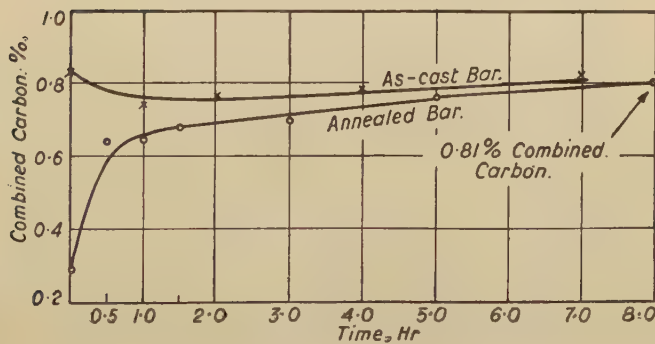
FIG. 8.—Bar No. 2 Heated at 900° C.

various temperatures. These curves show the rate of fall and in some cases the increase in combined-carbon content with increasing time of heating. The results obtained at 700° C. on the three irons bear some similarity, the combined-carbon content falling in both the as-cast and the annealed samples to about 0·18%, where it remained fairly constant with further heating. It appeared very difficult to remove this small amount of combined carbon, and examination of the structure showed that small amounts of pearlite seemed to be stabilised by the phosphide eutectic.

At 800° C. rather different results were obtained with the two
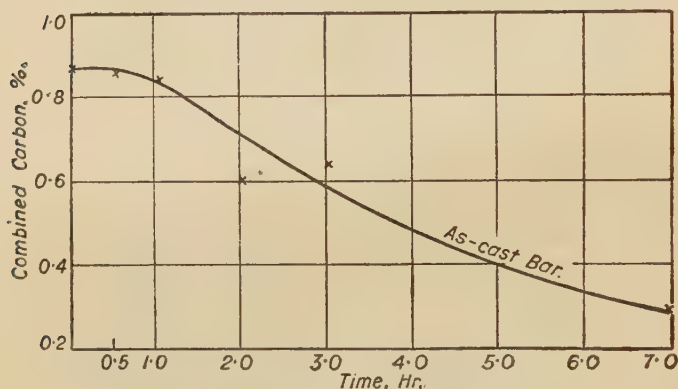
FIG. 9.—Bar No. 3 Heated at 700° C.

TABLE IV.—*Total, Graphitic and Combined-Carbon Contents of Bar 3 after Various Treatments.*

Time of Soaking. Hr.	As-Cast Sample.		
	T.C. %.	G.C. %.	C.C. %.
Heated at 700° C.			
$\frac{1}{2}$	3·40	2·54	0·86
1	3·41	2·57	0·84
2	3·39	2·79	0·60
3	3·39	2·75	0·64
4	3·42	2·94	0·48
7	3·40	3·10	0·30
Initial	...	...	0·87

bars 1 and 2. The 3% silicon iron No. 1 gave a similar curve to that at 700° C., the combined-carbon content dropping to about 0·18%, though in a shorter time than was required at 700° C. The

2% silicon iron, on the other hand, showed a drop in the combined-carbon content to about 0·46%. In the corresponding annealed bar there was an increase in the combined carbon until a figure of about 0·50% was obtained after 8 hr. heating. This figure thus represents the equilibrium combined-carbon content for the iron No. 2 at a temperature of 800° C., *i.e.*, the solubility of carbon in austenite at 800° C. for a 2% silicon cast iron.

A strong likeness exists between the curves for the as-cast and the annealed bars, indicating that the rates of decomposition and formation of combined carbon are similar.

The curves showing an increase or decrease in the combined-
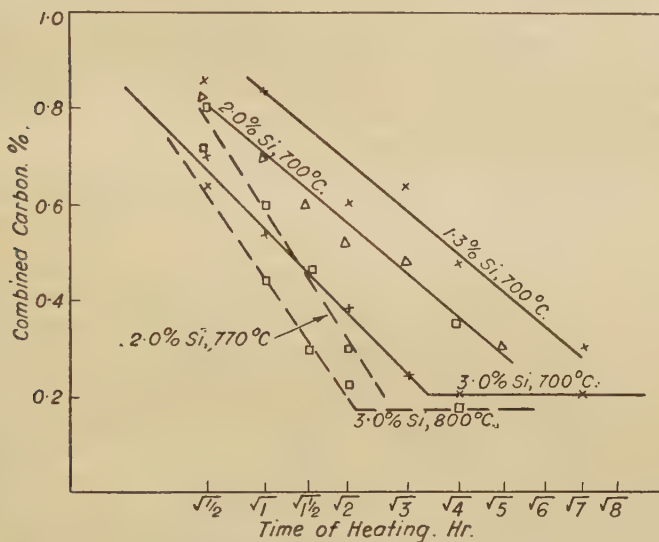
FIG. 10.—Relationship between the Combined-Carbon Content and the Time of Heating.

carbon content with increasing time of soaking bear a further significance when the time is plotted on a square-root scale; Fig. 10 contains some of the results so plotted. From this it will be seen that for a heating temperature of 700° C. there is very little difference in the rate of removal of combined carbon with a change in the silicon content. This appears contrary to the results of Kikuta [4] and also of White and Schneidewind, [2] who showed that the time to complete second-stage graphitisation (*i.e.*, below the critical point) in malleable cast iron decreases logarithmically with the increasing silicon content. The apparent divergence from the present findings may be explained if, as White and Schneidewind suggest, an increase of silicon in malleable cast iron promotes the

formation of more nuclei, leading to an increased rate of graphitisation. In the present instance, the irons were not heated above 700° C., so that no new nuclei could be formed, and, even if they were, their number would be very much outweighed by the preponderance of graphite flakes already present.

Whilst little difference in the graphitisation rate occurs with an increase in silicon content, there is a big increase in the rate of removal of combined carbon below the critical point on increasing the temperature above 700° C. This is shown by an examination of the graphitisation lines for the 2% silicon and 3% silicon irons at 700° C. and also at 770° C. and 800° C. respectively.

It would therefore appear that combined carbon may be removed more or less completely by heating at temperatures below the critical temperature Ac_1, and the nearer the heating temperature is to the critical point of the iron, the more rapid is the removed of the combined carbon. When the heating is conducted above the critical point, combined carbon may or may not be removed according to whether the initial combined-carbon content is above or below the equilibrium content for the temperature of the anneal. Thus, if the combined carbon is high, it will tend to fall to the equilibrium content as heating is prolonged, whilst it will tend to rise to the equilibrium content if it is low in the as-cast bar.

From the data obtained it would appear that the removal of combined carbon in grey cast iron is proportional to the square-root of the time of heating, which confirms the suggestion made by Schwartz and others that graphitisation is a diffusion phenomenon and follows similar laws to those governing the diffusion of solids in liquids. Additional evidence is found in the increase in the rate of graphitisation which is produced by raising the temperature of heating (while still keeping below the critical point), if it is assumed that the mobility of the carbon atoms is increased by a rise of temperature. On this argument, the similarity of the rates of graphitisation of the three irons at 700° C. would seem to show that silicon has little effect on the diffusion rate of carbon in iron.

Microstructure.

The structures of the samples heated at temperatures below the critical point appeared the most interesting. The heating period at 700° C. caused the pearlite to coalesce, and in the earlier stages of the anneal, *i.e.*, after $\frac{1}{2}$ and 2 hr., the carbide of the pearlite could be seen to be diminishing in amount near the graphite clusters, whilst a preponderance of carbide occurred near the phosphide eutectic. This change is shown in the photomicrographs (*see* Figs. 20 to 24) taken of the bar No. 2 heated at 700° C. The close laminations of pearlite near the phosphide eutectic can be seen becoming more open in texture and eventually disappearing as the graphite flakes are approached. Fig. 24, taken at 1200 diameters, illustrates the structure of a graphite flake in the sample

heated at 700° C. for 4 hr.   The deposition of graphite on the existing flake can be seen clearly, showing that the carbide of the pearlite has migrated to the flake and then broken down.   The deposited graphite gives a serrated appearance to the graphite flakes, when examined at high magnifications.

Solubility of Carbon in Austenite.

Some attention has been paid in the past to the question of the solubility of carbon in austenite under equilibrium conditions. Charpy and Cornu-Thenard [5] studied the influence of silicon on the solubility of carbon for carbon contents of 2% and a range of silicon of 2·23% to 6·77%.   These workers commenced by annealing their irons to remove all the pearlite, after which samples were heated at constant temperature for 1 to 3 hr., being then quenched in water.   The results obtained by those investigators are given in Table V.

TABLE V.—*Variation of Solubility of Carbon in Austenite with Varying Silicon Content (Charpy and Cornu-Thenard).*

Silicon. %.	Carbon, %, in Solution at—				
	600° C.	700° C.	800° C.	900° C.	1000° C.
2·23	0·0	0·0	0·6	0·8	1·1
3·16	0·0	0·0	0·0	0·7	0·9
4·22	0·0	0·0	0·0	0·2	0·7
5·84	0·0	0·0	0·0	0·0	0·3
6·77	0·0	0·0	0·0	0·0	0·2

Becker [6] has also studied the solubility of carbon in austenite for silicon contents up to 4%, using cementation experiments.   The results given by this worker relate only to slowly-cooled specimens and may not therefore be said to give an exact record of the maximum solubility of carbon in γ-iron at any particular temperature.

White and Schneidewind have also given an equilibrium diagram for iron-carbon-silicon alloys showing the effect of silicon on the solubility of carbon in austenite.

In order to throw light on this question, a number of $\frac{1}{2}$-in. sections from the bars 1, 2 and 3 were heated for periods of 10-hr. at various temperatures.   An electric furnace fitted with automatic temperature control was employed for this purpose.   In view of the results obtained in the previous experiments, it was considered that the specimens would have attained equilibrium at the end of the 10-hr. period.   After this time, the samples were rapidly quenched in water.   Samples were taken for analysis in the manner previously indicated, care being taken to discard about $\frac{1}{8}$ in. from the face of

the specimens to avoid any decarburisation. The results of the
combined-carbon determinations are given in Table VI.

TABLE VI.—*Solubility of Carbon in Austenite.*

Heating Temp. ° C.	1·3% Silicon Iron.			2·2% Silicon Iron.			3·2% Silicon Iron.		
	T.C. %.	G.C. %.	C.C. %.	T.C. %.	G.C. %.	C.C. %.	T.C. %.	G.C. %.	C.C. %.
750	3·40	3·20	0·20	3·45	3·25	0·20	3·30	3·18	0·12
	...	...	...	3·46	3·36	0·10	3·29	3·24	0·05
	...	...	...	3·42	3·37	0·05	3·31	3·11	0·20
775	3·42	2·84	0·58	...	...	...	...	...	...
	3·40	2·72	0·68	...	...	...	...	...	...
850	3·39	2·51	0·88	3·42	2·72	0·70	3·32	2·88	0·44
875	3·38	2·50	0·88	3·45	2·79	0·66	3·32	2·76	0·56
900	3·41	2·34	1·07	3·43	2·67	0·76	3·30	2·67	0·63
	3·40	2·36	1·04	3·40	2·66	0·74	3·33	2·74	0·59
	3·39	2·44	0·95	3·45	2·63	0·82	3·31	2·70	0·61

These results, together with those values derived from the
previous experiments, are plotted in Fig. 11, and though no extreme
accuracy can be claimed, they give some indication of the effect of
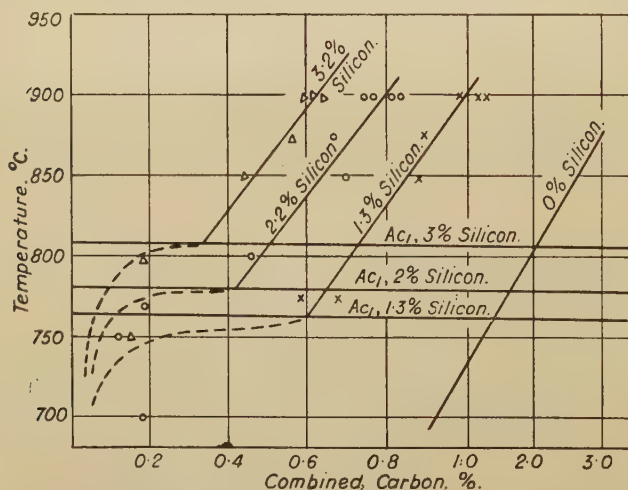
FIG. 11.—Relationship between the Silicon Content and the Solubility
of Carbon in Iron.

silicon on the solubility of carbon for the three irons for temperatures up to 900° C.

SUMMARY.

It has been shown that the annealing of grey cast iron involving the decomposition of pearlite may be readily accomplished at temperatures below the critical point, and that in such cases the rate of cooling after heating is of little importance. Annealing may be carried out at temperatures above the critical point, but when heating at constant temperature, pearlite will not be removed unless the initial combined-carbon content is above that denoted by the equilibrium for the particular temperature and composition of iron used. The major factor in the removal of pearlite by a high-temperature anneal is the rate of cooling after the anneal, the slower the rate of cooling the greater being the amount of pearlite which is removed.

Confirmation is given which shows that the removal of pearlite in cast iron at constant temperature is a diffusion phenomenon. The rate of graphitisation at temperatures below the critical point is increased by an increase in temperature, and the most successful method of removing pearlite in grey cast iron is to heat at a temperature as near to the critical temperature Ac_1 as possible. Silicon does not appear to affect the rate of graphitisation at constant temperature. However, the facility with which high-silicon irons anneal may be accounted for by the fact that the as-cast combined-carbon content is usually lower than for lower-silicon cast irons. The critical point is raised and the solubility of carbon decreased by an increase of silicon, which means that for a given temperature more pearlite may be removed than with an iron of lower silicon content.

Since the decomposition of pearlite becomes more rapid as the heating temperature is raised, the best method, particularly for high initial combined-carbon contents, will be to start the anneal at some temperature above the critical point, and to reduce the temperature at some predetermined rate to a final temperature of annealing in the region of the critical point. After this treatment the castings may be cooled as quickly as possible consistent with other factors such as the possibility of warping or cracking. Data are given for the solubility of carbon in iron for temperatures up to 900° C. for three different silicon contents.

The results obtained have a great bearing on the commercial annealing of grey cast iron, the most important feature being that softening can be obtained most easily and more completely by annealing at temperatures near the critical point of the iron concerned. If higher temperatures are employed, very slow cooling is necessary in order to remove all the pearlite and obtain maximum softness.

In most cases, the softening of cast iron for the production of

easily-machinable iron is carried out in a haphazard manner and usually at temperatures above the critical point. Needless time and money are spent on long soaking periods at these temperatures, and, more often than not, the subsequent rate of cooling is too fast to accomplish the desired softening. The use of a soaking temperature near the critical point of the iron enables the annealing operation to be carried out more economically and removes the necessity for the slow-cooling period.

This research also has a bearing on the annealing of cast iron in the enamelling industry. An annealing treatment is often carried out on such iron in order to remove dirt and occluded gases, and the temperature required involves the decomposition of the combined carbon; unless the whole of the combined carbon is removed, it is often found that the resultant castings are warped.

Cases have been met with, particularly in continuous annealing plants, where a high-temperature anneal with a too-rapid cooling stage has been employed. The pearlite in the resulting castings was only partially removed, and considerable warping occurred when the castings were enamelled. A change in the heating temperature to 800° C. (2·8% silicon iron) resulted in the whole of the pearlite being removed. The warping during enamelling on such castings was thereby reduced considerably.

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CORROSION OF STEELS BY MOLTEN NITRATES.*

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(Figs. 2 to 6 = Plates VII. and VIII.)

Synopsis.

The corrosion of steel containers by molten alkali nitrates is
important in the heat treatment of aluminium alloys in salt baths.
The process was investigated on a laboratory scale with special
reference to the effects of temperature, method of heat application
and impurity in the salt ; the influence of the material forming the pot
was also examined. It was found that, although the corrosion rate
increases rapidly with temperature, local overheating of the con-
tainer does not necessarily lead to accelerated corrosion at that
point. The scaling rate was found to be a function of the com-
position of the steel. Alkali chlorides, present as impurities in most
commercial salts, were found to stimulate corrosion. The equilibrium
between the alkali nitrates and nitrites was also investigated.

For the precise temperature control demanded in the heat treatment
of aluminium alloys it is usually found desirable to make use of a
fluid heating medium, and the furnaces most frequently installed
for the process are baths of molten salt. Suitable salts are sodium
nitrate, m.p. 309° C., or the equimolecular sodium-potassium nitrate
eutectic melting at 218° C. The advantage of the low-melting-point
mixture is that less strain is imposed on the salt container during
heating up and cooling down, so that for intermittent work the
employment of the eutectic is recommended. When a bath is to be
used continuously the melting point of the salt is less important.
From the point of view of heat treatment it is essential that the fused
salt shall have no undesirable chemical effect on the metal, and for this
reason it is sometimes specified that the salt shall contain no free
acid or alkali.

The salts are melted in open welded vessels of mild steel, externally
heated, and it is hardly surprising that under these circumstances
there is some oxidation of the vessel by the molten salts. In practice
it is found that some salt baths withstand this corrosion satisfactorily
while others are very rapidly attacked and are ultimately perforated,
so that the molten salt escapes and may do much damage. Exam-
ination of a number of installations where this had happened has
failed to locate the cause of the trouble and the problem has there-
fore been investigated in the laboratory.

Little work appears to have been published on the oxidation of

steel by molten nitrates. J. Lang [1] records that when saltpetre is heated to bright red heat the decomposition to potassium nitrite is not complete even if the heating is continued far beyond the point at which evolution of nitrogen peroxide begins. Free oxide of potassium is said to be formed and to attack iron crucibles very readily. When this happens a deposit of potassium ferrate is formed. The decomposition of sodium nitrate is said to be easier than that of the potassium salt, but in this case no ferrate is found. J. Scobai [2] states that pure potassium nitrate does not decompose at 410° C. and does not react with potassium chloride and chlorate at that temperature. The only contemporary work known to the authors is the German investigation of two serious salt bath explosions which took place in that country. [3] In one case perforation of the bath was ascribed to an intensification of the reaction between iron and molten alkali nitrate brought about by local overheating of the bottom of the bath in the presence of sludge. In the other case the cause of failure was thought to be the occurrence of a thermite reaction between aluminium scrap and loose iron oxide lying at the bottom of the bath, the heat developed being sufficient to melt the steel. Aluminium was found to be inert to the molten nitrates at all temperatures up to its melting point (657° C.), so that severe local overheating must first have taken place. General experience, however, shows that pot failure is most commonly caused by local corrosion, not necessarily at the bottom of the pot or at an over- heated surface, producing a heavy growth of laminated scale and gradually eating into the metal until it is perforated. No cases of the explosive thermite reaction have been within the personal experience of the authors, but although the effect is unusual it is obviously desirable to prevent any foreign matter from accumulating on the bottom of the bath.

Experimental Work.

It was decided that the laboratory work must reproduce as nearly as possible the conditions prevailing in practice, and the tests were therefore carried out on miniature welded pots made of 22-gauge metal and measuring 2 in. square × 6 in. deep; 200 g. of fused salt about half filled a pot. The area of metal surface in contact with the molten salt was 24 sq. in. (154·8 sq. cm.). Nine of these pots were heated in a furnace, shown in Fig. 1, which was specially designed to heat them as uniformly as possible, with the burner placed at some distance below them, so that all possibility of flame contact was avoided. The gas supply to the furnace was governed and accurate temperature control could be maintained. Temperatures were measured by silica-sheathed platinum/platinum- rhodium couples placed in the salts, using a Cambridge indicator. The maximum variation from end to end was not greater than 7° C. at 500° C. and 10° C. at 600° C., and during a 1000-hr. test the maximum variation in any pot was not greater than ± 3° C.
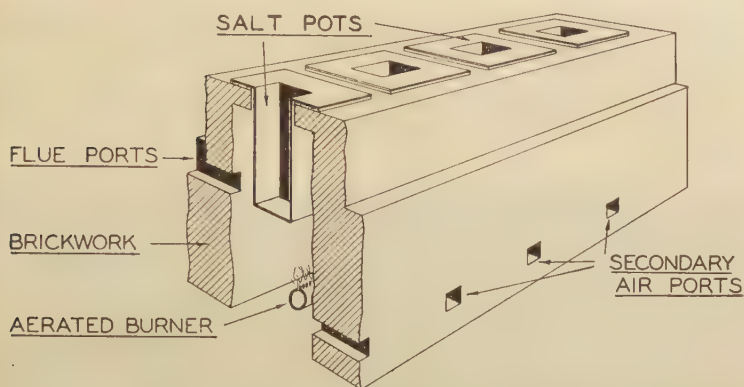
FIG. 1.—Diagram of the Furnace Designed for the Heating Experiments.

(1) General Overheating.

Two series of tests were carried out, one at 500° C., a normal working temperature, and the other at 600° C.; heating was continuous and no aluminium was immersed in the salts. The results are given in Tables I. and II.

TABLE I.—*Effect of General Overheating at 500° C.*

Pot No.	Salt.	Cl′. %.	SO₄″. %.	Time. Hr.	Gain in Weight. G.	Remarks.
	Ingot Iron. *Carbon*, 0·05%.					
1	Commercial sodium nitrate	0·40	0·19	350	...	Thin layer of black adherent scale.
3	Commercial eutectic + 1% nitric acid	0·18	0·09	350	...	Thin layer of black adherent scale.
4	Commercial eutectic + chloride + sulphate	0·36	0·57	350	4	Unchanged except for a trace of loose scale.
	Mild Steel. *Carbon*, 0·13%.					
5	Commercial sodium nitrate	0·40	0·19	350	20	Large loose flakes of scale.
6	Commercial eutectic	0·18	0·09	350	13	Large loose flakes of scale.
8	Commercial eutectic + chloride + sulphate	0·36	0·57	350	26	Large loose flakes of scale.
9	Pure eutectic *	Nil	Nil	350	...	Unchanged.

* Analytical reagents.

External corrosion took the form of powdery red oxide, giving a velvety appearance, but the amount was negligible in comparison

with that occurring internally in pots 5, 6 and 8. No loose flakes of scale were produced on the outside of the pots in these or any of the subsequent tests.

There was a suggestion that in pot 5 the corrosion might centre around the weld, but this effect has not been observed in any of the later tests.

TABLE II.—*Effect of General Overheating at 600° C.*

Pot No.	Salt.	Cl'. %.	SO₄''. %.	Time. Hr.	Gain in Weight. G.	Remarks.
	Ingot Iron. Carbon, 0·05%.					
11	Commercial sodium nitrate	0·40	0·19	350	9	Adherent layer of scale.
12	Commercial eutectic	0·18	0·09	350	10	Adherent layer of scale and a little loose flaky scale.
13	Commercial eutectic + chloride + sulphate	0·36	0·57	350	8	As No. 12, but with a considerable amount of loose flaky scale.
14	Commercial eutectic + 1% nitric acid	0·18	0·09	350	9	As No. 12, but a little more loose scale.
	Mild Steel. Carbon, 0·09%.					
15	Commercial eutectic	0·18	0·09	350	22	Heavy growth of laminar scale and some loose flakes.
16	Commercial eutectic + 1% nitric acid	0·18	0·09	350	18	Heavy growth of laminar scale and some loose flakes.
17	Pure eutectic *	Nil	Nil	350	6	Some flakes of adherent scale.
18	Pure eutectic + chloride *	0·61	Nil	48	44	Perforated after 48 hr.
19	Pure eutectic + sulphate *	Nil	0·68	350	31	Heavy growth of laminar scale.

* The " pure " salts used were in all cases analytical reagents.

The results show that there is a marked increase in the rate of corrosion at the higher temperature, particularly when comparison is made between runs 1, 3 and 4 and runs 11, 12, 13 and 14, all on a low-carbon iron. An ordinary brand of commercial salt, as used in heat-treatment practice, was chosen for the experiments, with impurities artificially increased where shown. It is particularly interesting to note the behaviour of pot 18, in which a chemically pure sodium-potassium eutectic to which 0·61% of chlorine had been added as NaCl, was used; corrosion was very rapid and a large circular hole appeared in the pot within 48 hr.

The results obtained are very similar to those recorded on actual

PLATE VII.

FIG. 2.—Typical Appearance of a Corroded Pot. The external attack is negligible compared with the internal. The laminar growth of scale on one side is clearly visible.

PLATE VIII.

Fig. 3.—Sample *K*, after 200 hr. at 500° C. in pure NaNO₃. Unetched. × 100.

Fig. 4.—Sample *N*, after 200 hr. at 500° C. in pure NaNO₃. Unetched. × 100.

Fig. 5.—Sample *M*, after 200 hr. at 500° C. in pure NaNO₃. Unetched. × 100.

Fig. 6.—Scale Fragment from a Punctured Salt Bath.

[*Lloyd and Chamberlain.*
[*To face p.* 145 P.

installations. The corrosion is localised—for instance one side of a pot may be badly scaled while the rest of it is virtually untouched. A typical corroded pot is shown in Fig. 2. The laminar growth of scale on one side is clearly visible. The external attack is in every case negligible compared with the internal. The rapid perforation of pot 18 is analogous to the very sudden failure which sometimes occurs under industrial conditions. General overheating is, however, unlikely in practice, since the heat treatment of the alloys requires very close control of temperature and automatic regulation is almost universal.

(2) *Local Overheating.*

A small furnace holding a single experimental pot was built, the pot being heated by a single aerated Bunsen burner firing on to the side of the pot. Two tests were made, one at 500° C. and the other at 600° C. on mild-steel pots (carbon 0·09%) with the commercial nitrate eutectic used in the previous experiments. The pot heated to 500° C. had a coloured zone on the outside where the flame had played but showed no sign of local corrosion inside or out, except one pimple of scale on the side remote from the flame. The pot which had been heated to 600° C., similarly, showed no local corrosion where the flame had played, but contained the same laminated iron-oxide scale as the pots heated to 600° C. normally. These experiments have been repeated and the results confirm that local heating does not in itself produce corrosion at that point. All the following tests were done at the standard temperature of 500° C.

(3) *Effect of Variations in Composition of the Steel Forming the Pot.*

The results already quoted, Tables I. and II., give evidence of the varying resistance of different steels to the corrosive attack and suggest that iron sheet of low carbon content is superior to mild steel. Other early tests showed considerable differences between various mild steels. To investigate this point further a supply of four different sheets was obtained, the analyses being as follows :

Steel.				Carbon. %.	Sulphur. %.	Phosphorus. %.	Manganese. %.	Silicon. %.
K	.	.	.	0·09	0·03	0·06	0·4	0·04
L	.	.	.	0·13	0·05	0·06	0·37	0·07
M	.	.	.	0·03	0·032	0·008	0·017	Nil
N	.	.	.	0·05	0·04	0·006	0·02	Nil

The published evidence on the effect of carbon content and other impurities on the scaling of steels at this temperature is scanty. Preece, Simister and Cobb [4] concluded that at 650° C. the carbon content of a steel has no appreciable influence on the corrosion rate. Siebert, [5] working at much higher temperatures, 930–1150° C., found that all carbon steels behaved similarly but Armco iron was anomalous.

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A preliminary test was made to determine the corrosion of the four steels in air at 500° C. Samples were cut approximately 2 in. square, degreased with benzene, washed with ether and dried *in vacuo* before weighing. After heating in a muffle at 500° C. for 500 hr. the samples were cooled *in vacuo* and weighed. To obtain a comparison with the rate of oxidation in pure molten nitrate at the same temperature, similar strip samples were suspended in a large salt pot for 500 hr. The results of the two tests are given below :

Sheet.				Weight before Heating. G.	Increase in Weight after Heating in Muffle. G.	Increase in Weight. Mg. per sq. cm.	Increase in Weight after Heating in Molten Salt. Mg. per sq. cm.
K	.	.	.	19·790	0·397	7·35	41·6
L	.	.	.	19·722	0·413	7·45	...
M	.	.	.	15·295	0·408	7·5	15·9
N	.	.	.	20·680	0·436	7·75	15·8

In the muffle test there was little difference in the amount of scaling of the four samples, but it was found that K, L and M, instead of forming the laminar scale typical of the salt-bath tests, had a patina of red oxide, velvety in appearance and similar to the oxidised surface on the outside of the salt pots. The sheet N, on the other hand, had the characteristic laminar scale. In the salt-bath tests the scaling rates were appreciably higher and there was also an obvious difference between M, N and K.

Tests with molten sodium nitrate (chlorine, 0·25%) at 500° C. in sample pots as previously described are listed in Table III., and the results may be summarised as follows :

> *Sheet K.*—Four test pots, marked local attack in every case, leading to perforation in one instance.
> *Sheet L.*—Two test pots, one perforated, the other the most heavily scaled of its batch.
> *Sheet M.*—Five tests, no local attack in any instance.
> *Sheet N.*—Four tests, local attack in each case, but no perforation, and increase in weight less than with K and L.

The superiority of M (Armco iron) is obvious, but whether the difference is due to the low carbon content, to absence of other impurities or to lack of segregation is not clear from the evidence at present available. It is worth recording the fact that practical experience of salt baths fully confirms the conclusion as to the resistance of Armco iron to this form of attack.

Analysis of the laminar scale formed on steel K showed that it consisted of 99% Fe_2O_3. Sections of K, M and N in the early stages of scaling, *i.e.*, after 200 hr., in pure sodium nitrate at 500°C. are shown in Figs. 3, 4 and 5. The mild steel K shows a discontinuity of structure suggestive of a laminar form, and the wavy outline may indicate strains in the oxide layer tending to split it away from the

surface.   The Armco iron M, by contrast, has a thinner and much more uniform scale structure, while N is intermediate.   Fig. 6 shows a micrograph of a piece of scale from a punctured mild-steel bath out of an actual furnace.   The irregular curvature of the scale layers is again in evidence.   A micrographical examination of samples of the four scaled steels was made by Mr. A. Preece, of Leeds University, but this gave no evidence of intercrystalline corrosion. Work on the mechanism of scaling of various steels under these conditions and in particular on electrolytic effects is now in progress.

TABLE III.—*Influence of the Composition of the Pot on the Corrosion.*

Sodium nitrate (Cl′, 0·25%) at 500° C.

Pot No.	Metal.	Time to First Sign of Corrosion. Hr.	Total Time of Test. Hr.	Increase in Weight. G.	Remarks.
C.1	K	36	504	4·2	General attack and several large blisters.
C.4	M	...	504	5·0	Clean, no visible corrosion.
C.5	L	24	504	12·1	Large loose flakes of scale and general attack.
C.6	M	...	504	2·0	Clean, no visible corrosion.
C.7	N	...	504	5·0	Single large blister, other surfaces clean.
C.10	K. Al-sprayed outside	144	264	16·0	Corrosion one side of pot only.
C.13	M. Al-sprayed outside	...	1570	Nil	No sign of corrosion.
C.14	N. Al-sprayed outside	384	1570	12·0	General corrosion inside and outside, loose scale.
C.15	L. Al-sprayed outside	24	1570	15·0	Rapid formation of laminated scale, bottom perforated.
C.20	K	48	1000	17·0	Very heavy laminar scale on 3 walls.
C.21	K. Al-sprayed outside	120	456	42·0	Heavy corrosion, two sides perforated.
C.23	M. Al-sprayed outside	...	1000	3·5	Clean.
C.24	M	...	1000	2·5	Clean.
C.25	N. Al-sprayed outside	...	1000	4·5	Two large areas of attack, otherwise clean.
C.26	N	96	1000	3·0	One large area of attack, otherwise clean.

In this test pot *C*.14 was abnormal in showing external as well as internal corrosion.

As the first test on the protection of miniature pots by metal spraying (C.8 and C.9 in Table IV.) gave promising results, the further tests listed in the Table were made.

TABLE IV.—*Tests with Pots Protected by Metal Spraying.*

Sodium nitrate (Cl′, 0·25%) at 500° C.

Pot No.	Material.	Time to First Sign of Corrosion. Hr.	Total Time of Test. Hr.	Increase in Weight. G.	Remarks.
C.1	K	36	504	4·2	General attack, several large blisters.
C.8	K. Al-sprayed inside and out	...	504	1	No sign of corrosion.
C.9	K. Stainless-steel - sprayed inside and out	...	504	1	Single small blister of scale, salt pale green.
C.10	K. Al-sprayed outside only	144	264	16	Corrosion on one side of pot only.
C.11	K. Al-sprayed inside and out	12	264	18	Immediate flaking of the aluminium and corrosion.
C.12	K. Al-sprayed inside and out and heat - treated	...	1570	Nil	Aluminium coating on outside pealing, inside clean.
C.19		...	1000	1	Clean, no visible attack.
C.21	K. Al-sprayed outside	120	456	42	Heavy corrosion, two sides punctured.
C.22	K. Al-sprayed inside and out	120	1000	28	Heavy corrosion on three sides.

The heat treatment given to pots C.12 and C.19 was that recommended by Rollason.[6] After spraying, the pots were coated with bituminous paint, heated rapidly to 780° C. and maintained at this temperature for 10 min. After cooling in air they were heated at 900° C. for 5 hr. and quenched in water.

These results show that aluminium-spraying alone, though it may be helpful, offers no certain protection. The heat-treated pots, on the other hand, were promising, and by way of further investigation of this form of protection a commercial process was investigated. Two pots, CXC and CXC2, made of steel K treated in this way, showed the first signs of corrosion after 240 hr.; the tests lasted 576 and 744 hr., respectively, and the increase of weight was 18 g. in each case. At the end of the test pot CXC was punctured and pot CXC2 nearly so.

It seems that protection by these processes is unreliable and that the use of Armco iron is a preferable solution to the problem. To

eliminate effects due to differences between steels all the following work on salt composition was done with the mild-steel sheet K, the analysis of which is given on p. 145 P.

(4) *Effect of Impurities in the Salt.*

In the many test runs completed during this investigation no evidence has been obtained of any difference between the corrosive effects of the sodium salt and the eutectic. The point is illustrated by the comparison of pots 5 and 6, 11 and 12, and others, but greater significance attaches to the result of pots 9 and 17 containing the pure eutectic, since in each of these cases corrosion was at a minimum. The important conclusion from the preliminary tests of Tables I. and II. is that impurities in the salts cause a very marked acceleration of the corrosion. The impurities investigated, chlorides and sulphates, are those which are actually present in most commercial salts, chlorides being the most common. Their effect was further examined by carrying out a series of tests at 500° C. with varying concentrations of alkali chloride, and the results are given in Table V.

TABLE V.—*Effect of Chloride in the Bath on the Corrosion.*

Steel K.   Period of test, 500 hr.   Temperature, 500° C.

Pot No.	NaNO₃. G.	NaCl. G.	Cl′. %.	Increase in Weight. G.	Remarks.
$C.45$	200	Nil	Nil	1	Slight corrosion on two sides.
$C.46$	200	0·33	0·1	11	Laminar scale on sides, also external corrosion leading to ultimate perforation.
$C.47$	200	0·66	0·2	38	Very heavy laminar scale.
$C.48$	200	0·99	0·3	42	Very heavy laminar scale.
$C.49$	200	Nil	Nil	5	No internal scale, but heavy external corrosion leading to ultimate perforation.
$C.50$	200	0·33	0·1	10	Slight corrosion.
$C.51$	200	0·66	0·2	13	Moderate corrosion.
$C.52$	200	0·99	0·3	17	Heavy corrosion.
$C.53$	200	Nil	Nil	Nil	No corrosion.

Heavy corrosion began to occur in less than 16 hr. in all pots containing chloride, and the growth of laminated oxide scale continued throughout the test. The three pots containing pure nitrate remained free from corrosion. The increase in weight of pots $C.45$, $C.46$, $C.47$ and $C.48$ is most significant, and it was realised that 0·1% of chlorine has a marked accelerating effect on the rate of corrosion on this particular mild steel. Pots $C.46$ and $C.49$ are abnormal in having suffered external corrosion leading finally to perforation.

Further experiments were then made to determine the smallest

quantity of chloride which has a significant effect on the rate of corrosion at 500° C. As Table VI. shows, there is a measurable

TABLE VI.—*Minimum Chloride Content in Bath Causing Corrosion.*

Steel K. Period of test, 1000 hr. Temperature, 500° C.

Pot No.	NaNO₃. G.	NaCl. G.	Cl'. %.	Increase in Weight. G.	Remarks.
C.55	200	Nil	Nil	Nil	No scale.
C.56	200	0·33	0·1	7·0	Local attack.
C.57	200	0·165	0·05	5·0	,, ,,
C.58	200	0·0825	0·025	4·0	,, ,,
C.59	200	Nil	Nil	Nil	No scale.
C.60	200	0·33	0·1	10·0	Local attack.
C.61	200	0·165	0·05	4·0	,, ,,
C.62	200	0·0825	0·025	Nil	No scale.

acceleration in corrosion with chlorine-ion concentrations as low as 0·025%, and the rate of corrosion increases with increasing chlorine-ion concentration.

The two sets of experiments listed in Table V. and VI. indicate the importance of using salt with the lowest possible chloride content. Even salts sold specially for heat-treatment work may contain 0·3% of chlorine-ion, while it has been found that salts containing still higher chloride concentrations are in use. The effect of chloride on the rate of corrosion is closely linked with the quality of the steel used for the bath, and with those steels that are intrinsically resistant to this form of corrosion the chloride concentration in the salt is less serious.

Later tests have failed to confirm the earlier suggestion that sulphates had an accelerating effect on corrosion. Two pots, C.71 and C.72, were charged with 200 g. of sodium nitrate containing 0·6 and 0·3% of sulphate respectively, and heated at 500° C. After 800 hr. neither of them had increased in weight at all. In any case the sulphate concentration in most commercial salts is now very low.

(5) *Tests on Commercial Salts.*

Three typical commercial nitrate mixtures were analysed for chloride and sulphate impurities with the following results :

	Cl'. %.	SO₄''. %.
Mixture A	0·3	Trace
Mixture B	<0·1	,,
Mixture C	0·09	,,

The tests made with them were run at 500° C. for 1000 hr. The results are listed in Table VII.

TABLE VII.—*Corrosion by Commercial Salts.*

Steel *K.*

Pot No.	Salt Used.	Time to First Visible Corrosion. Hr.	Increase in Weight. G.	Analysis of Melt.		Remarks.
				Cl'. %.	SO₄''.	
C.63	Mixture A	48	12	0·3	Trace	Patches of corrosion products on three walls, one zone of laminated scale at salt level.
C.64	Mixture C	190	7	0·09	,,	Two areas of local scale formation with detached flakes. Several small areas of attack with flakes adhering.
C.65	Mixture B	190	5	0·1	,,	Slight general corrosion, but no marked local attack.
C.66	Mixture A	48	10	0·3	,,	Similar to C.63 but laminated scale on base of pot.
C.67	Mixture C	190	9	0·09	,,	One large area of attack with loose laminated scale layer, surfaces clean.
C.68	Mixture B	190	7	0·1	,,	As No. C.65.
C.69	Control, pure NaNO₃	...	2	Nil	Nil	No visible corrosion.

The results generally confirm that the chloride concentration is the factor controlling the corrosive properties of these salt mixtures.

(6) *The Reactions in the Salt.*

The oxidising effect of the molten nitrates is due to decomposition to nitrite with liberation of oxygen. These reactions, *e.g.*, $2NaNO_3 = 2NaNO_2 + O_2$, were investigated by M. Centnerszwer,[7] who found them to be reversible. He measured the temperature of initial decomposition under different oxygen pressures with the following results :

Sodium Nitrate.		Potassium Nitrate.	
Oxygen Pressure. Mm. Hg.	Temperature. °C.	Oxygen Pressure. Mm. Hg.	Temperature. °C.
304	480	368	489
434	493	523	505
606	511	586	513
719	523	686	525
774	530	768	533
829	536	840	538

With pure salts it follows that the heat-treatment temperature of 500° C. corresponds to a dissociation pressure well in excess of the partial pressure of oxygen in air, but less than atmospheric pressure. Under these circumstances slow decomposition might be expected without effervescence. The dissociation curve of the binary mixture of the sodium and potassium salts (in pure oxygen) was found to give a minimum at 485° C., corresponding to the molecular proportions 30% NaNO₃ : 70% KNO₃. The dissociation temperature for the eutectic was about 496° C.

The same investigator measured the effect of additions of sodium

and potassium nitrites on the dissociation temperatures of the corresponding nitrates (again in equilibrium with oxygen). He found that there was a very marked raising of the dissociation temperature :

Sodium Nitrate with Additions of Sodium Nitrite.			Potassium Nitrate with Additions of Potassium Nitrite.		
$NaNO_2$. %.	Oxygen Pressure. Mm. Hg.	Temp. ° C.	KNO_2. %.	Oxygen Pressure. Mm. Hg.	Temp. ° C.
0	262	476	0	245	494
1	256	539	1	257	529
2	263	547	2	245	560
3	265	563	3	242	576
5	262	567	5	245	604·5
7	263	596	7	242	621

In practice there seems to be effervescence from every sample on first melting, and in some cases the reaction proceeds vigorously. Later the effervescence dies down and when the pot is not corroding it appears as if the decomposition of the salt has ceased. Evolution of nitrogen peroxide has never been observed even in the tests at 600° C.

The question arises how far the decomposition of nitrate to nitrite proceeds in salt baths. The German Reichsarbeitsblatt [3] (loc. cit., p. 313) gives the following analyses of residual salts from nitrate baths, one specimen having been taken from a bath which had exploded as a result of overheating :

					Exploded Bath.	Other Commercial Baths.		
Nitrate. %	.	.	.	.	52·2	66·5	89·9	97
Nitrite. %	.	.	.	.	9·6	4·4	3·9	1·2
Nitrate/nitrite ratio	.	.	.	5·4	15·1	23·1	81
Alkali oxide. %	.	.	.	.	1·3	0·2	0·03	0·02

A process patented by the I.G. Farbenindustrie A.G. [8] claims the use of alkali dichromates to re-oxidise the nitrite and to decompose free alkali, aluminate and ferrate with the object of reducing scaling of the bath.

Analyses of the commercial salts and of pure sodium nitrate after heating in pots C.63–C.69 (Section 5) gave the following results * :

Pot No.	Salt.	Nitrite as $NaNO_2$. %.	Free Alkali as Na_2O. %.
C.63	A	2·0	
C.64	C	1·5	Not measured
C.65	B	1·0	
C.66	A	3·36	0·67
C.67	C	0·78	0·11
C.68	B	0·87	0·17
C.69	Pure sodium nitrate	0·62	0·01

* In order to obtain consistent results in the volumetric determination of nitrites, it was found necessary to modify the method of Lunge (Berichte der deutschen chemischen Gesellschaft, 1877, vol. 10, p. 1075) given by Treadwell and Hall ("Analytical Chemistry," 1935, eighth edition, p. 570). The procedure adopted was to add an excess of potassium permanganate to the solution containing the nitrite, acidify with 0·75N sulphuric acid, warm to 40° C., and back-titrate the excess permanganate with ferrous ammonium sulphate.

All samples showed traces of iron but not sufficient to be detected with ammonia. Of the fresh salts both A and C contained similar traces of iron. A similar examination of salts collected from actual heat-treatment baths in commercial use gave the following results :

Sample No.	History.	Nitrite as $NaNO_2$. %.	Cl'. %.	Na_2O. %.
1	Commercial mixture D, Armco pot in use 9 months	2·1	0·08	...
2	Commercial mixture E, Armco pot in use 4 months	9·0	0·21	0·15
3	Commercial sodium nitrate F, Armco pot in use 10 months	3·1	0·11	0·27
4	Commercial mixture G, mild-steel pot in use 2 months	0·75	0·07	...
5	Commercial mixture H, mild-steel pot in use 5 months	1·85	0·24	...

Of the commercial mixtures concerned in these tests, A and E were abnormal in containing additions of nitrite.

A number of model pots were next heated with added nitrite present to ascertain the effect on the corrosion of the steel and on the liberation of free alkali. Standard mild steel pots were used in every case. The results are reproduced in Table VIII.

TABLE VIII.—*Effect of Nitrite in the Bath on the Corrosion.*

Steel K.   Temperature 500° C.

Pot No.	Charge.	Time to First Sign of Corrosion. Hr.	Total Time of Test. Hr.	Weight Increase. G.	Remarks.
C.73	NaNO₃ + 0·5% NaCl	72	798	9	Heavy corrosion, one large patch and two small.
C.74		72	798	21	One large and one small patch of corrosion.
C.75	NaNO₃ + 0·5% NaCl used on a previous run	...	370	1	No local attack.
C.76	NaNO₃ + 0·5% NaCl + 1·5% NaNO₂	106	370	17	One patch of laminar scale.
C.77	NaNO₃ + 0·5% NaCl + 3·0% NaNO₂	106	370	18	Two patches of laminar scale.
C.78	Pure NaNO₃	...	1,012	Nil	No visible corrosion.
C.79	NaNO₃ + 0·5% NaCl + 7·5% NaNO₂	...	500	2	No visible corrosion.
C.80	NaNO₃ + 0·5% NaCl + 15% NaNO₂	...	500	0	No visible corrosion.
C.81	Salt from pot No. 75	...	1,004	2	No visible corrosion.

Analysis of the residual salts from these tests yielded the following results :

Pot No.	$NaNO_2$. %.	Na_2O. %.
C.76	2·65	0·4
C.77	3·75	0·4
C.79	3·7	0·25
C.80	10·3	0·15

On the other hand, a sample from an Armco-iron pot containing pure sodium nitrate which was heated for 3000 hr. at 500° C. had only 0·4% of $NaNO_2$ with 0·1% of Na_2O.

The results are interesting in various ways. They show that under commercial conditions the nitrite concentration tends to rise gradually, but that the decomposition of the nitrate does not approach completion at these temperatures. It is impossible on the evidence from industrial installations to decide whether a true equilibrium is established, since there is always a steady wastage of salt which is made up by addition of fresh material to the bath. The presence of appreciable quantities of free alkali oxide after prolonged heating is interesting in showing the doubtful value of fixing limits to the permissible alkalinity of the original salt. The high concentration of free alkali in the salt residue from pot C.66, which contained a commercial salt with nitrite addition, is suggestive, but the later investigation of the effect of increasing nitrite concentrations (pots C.76, C.77, C.79, C.80) shows that increase in the initial nitrite concentration actually reduces the percentage of free alkali developed.

The corrosion tests on pots C.73–C.81 indicate clearly that, while small additions of sodium nitrite, 1·5% and 3·0%, have no great effect on the corrosion rate, larger additions, 7·5% and 15%, are effective in suppressing it. The analyses of the residual salts fully explain the corrosion effects, since it is seen that the salts containing the lower nitrite concentration have continued to decompose with liberation of oxygen, while the others, instead of having an oxidising effect, have themselves been oxidised by the atmospheric oxygen. The results are clearly consistent with Centnerszwer's figures for the effect of nitrite on decomposition temperatures and suggest that in air (partial pressure of oxygen, 159 mm.) and at 500° C. the equilibrium mixture of the sodium salts contains about 4% of nitrite. Centnerszwer's decomposition temperatures for the sodium-potassium nitrate mixtures suggest that in the equimolecular mixture the nitrite percentage at equilibrium may be considerably higher, which may account for the poor performance of the commercial salt mixture with the nitrite addition. In practice the equilibrium is not always reached on account of the slowness of the reaction in pure salts—*cf.* the result of the 3000-hr. test. On the other hand, the equilibrium may also be displaced by over-heating, as in the German results, and possibly by electrolytic effects.

No other chemical reactions of any significance have been detected in the molten salt. Impure salts often give a brownish flocculent precipitate, but the quantity is very small and it has not been possible to isolate sufficient of the deposit for analysis. The traces of chloride which have been found to exert such a marked effect on the course of the corrosion are still found to be present in the same concentration at the end of a test run.

Conclusions.

The corrosion of steel by molten alkali nitrate has been investigated with special reference to the effects of temperature and of impurities in the salt.   It was found that the scaling which takes place under these conditions is different both in character and in extent from scaling in a gaseous medium at the same temperature. Although the rate of oxidation increases markedly with rise in temperature, local heating of a part of the metal container does not in itself give rise to abnormal scaling at that point.   Exploratory tests on certain irons and steels showed that Armco iron had a high resistance to this form of corrosion; investigation of this aspect of the problem is continuing.   The protection provided by aluminium coatings was uncertain.   Alkali chlorides are common impurities in the commercial salts used for the heat treatment of light alloys, and it was found that they are responsible for a marked acceleration in the rate of attack on the steel; 0.1% exercises a considerable in- fluence.   It was found that decomposition of nitrate to nitrite does not proceed to completion and that salt mixtures containing much nitrite are oxidised by the atmospheric oxygen.   In one series of tests with sodium salts at 500° C. and in air the equilibrium concentration of nitrite was found to be about 4% .   It is concluded that with the sodium salt the presence of 5% or more of nitrite should be helpful in suppressing the corrosion, but with the eutectic a greater addition may be necessary on account of the lower intrinsic dissociation temperature.

Acknowledgments.

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CORRESPONDENCE.

Mr. W. E. BALLARD (Dudley) wrote that he was greatly interested in this paper, because, as the authors remarked, little work seemed to have been carried out on the phenomenon of localised oxidation of salt baths, although it had been the cause of many commercial difficulties.

The authors indicated that aluminium-spraying, followed by the aluminising process, appeared to give unreliable results. Commercial experience had not confirmed this observation, and it was probable that the failure to obtain more reliable results in the experimental test was due to the treatment of quenching the aluminised articles in water, which was no part of commercial treatment but was a method of testing to destruction. It would also be interesting to know whether the thickness of the aluminium coating was checked, as the correct thickness was an important matter. If the coating were too thin obviously protection would be limited, and if too thick the aluminium-iron alloys formed by absorption tended to fissure, owing to differential expansion. A coating of 0·007–0·008 in. was recommended.

The authors did not investigate the effect of slag inclusions in the steel, but such inclusions might have a very important bearing on the case. The presence of silica particles in molten nitrates had been found to bring about chemical reaction, apparently by catalysis. Some similar reaction had, the writer believed, been observed in smouldering pit banks owing to the presence of free silica.

The metal-spraying of Nichrome on to salt baths had also been found to be successful in combatting corrosion from molten nitrates, but its use had not been developed, owing to the high cost of sprayed Nichrome compound in comparison with the cheaper process of aluminising.

The paper was an extremely useful one from a practical point of view, because users of salt baths did not as a rule take sufficient precautions with them. The salt itself was seldom checked for impurities and often no precautions were taken to avoid the presence of foreign bodies such as pieces of refractory lining and sand from the floor. It was hoped that this paper would lead to more attention being paid to these matters.

Mr. R. A. PARKES (Dudley) wrote that the authors' conclusions regarding impurities existing in the original nitrates were extremely valuable, although they had not taken into consideration the possible effect of foreign matter entering the salts while the baths were in operation.

Some years ago the writer had occasion to investigate one or two cases of severe local scaling inside nitrate baths, and came to the conclusion that small quantities of silica from the refractory

linings, becoming admixed with the nitrates, had a considerable bearing on the matter. One would not expect the temperature to be high enough for the silica to decompose the nitrates, but the indications were that this reaction had taken place, with the evolution of nitric anhydride. Subsequent tests in the laboratory proved conclusively that the presence of small amounts of silica had a marked effect on the scaling of steel immersed in molten nitrates.

This led to the possibility that slag inclusions at or near the surface of the steel might have a similar effect, and, as a precaution, plates subsequently used for the manufacture of the baths were thoroughly pickled and the surfaces examined for such defects. It was also deemed advisable to use steel with a minimum silicon content, and it is significant that, of the steels tested by the authors, those free from silicon gave the best results generally, although no importance appeared to have been attached to this fact.

The writer was particularly interested in the tests carried out on protective coatings of aluminium applied by the metal-spraying process. These deposits without subsequent heat treatment were not normally recommended for salt-bath protection, although satisfactory results had been reported from various quarters. Satisfactory protection by this means would depend upon strict temperature control, not only of the salt but also of the bath itself, where unsuspected overheating might occur.

Sprayed aluminium coatings followed by the correct heat treatment had given remarkably successful results, not only in pro-tecting the baths internally and externally but also in preventing contamination of the nitrates in contact with the bath walls.

The authors had, unfortunately, misinterpreted Rollason's recommendations for heat treatment, the operation of reheating to 900° C. and quenching in water actually being part of the destructive tests which Rollason imposed, and not an integral part of the process itself. Had this second heat treatment been omitted there was no doubt that the results would have been better than the authors found, and certainly more consistent.

Dr. J. C. HUDSON (Birmingham) wrote that the authors' data given on p. 146 P for the oxidation of four steels agreed reasonably well with the values recorded by other investigators, taking into consideration the marked effect of the experimental conditions on the results obtained in this type of test. Their average weight increment of 7·5 mg. per sq. cm. after this period corresponded to an oxidation rate of 0·00005 in. per hr., assuming that the scale contained 75% of iron and that the oxidation varied as the square root of the time.[1] The probable value for the rate of oxidation in air at 500° C. lay between 0·00002 and 0·00004 in. per hr. For

[1] J. C. Hudson and T. E. Rooney, "Review of Oxidation and Scaling of Heated Solid Metals," p. 56. London, 1935 : H.M. Stationery Office.

instance, Hatfield [1] observed a weight increment of 0·622 mg. per sq. cm. on heating mild steel in air for 24 hr.; this would correspond to about 2·8 mg. per sq. cm. over 500 hr. If the present authors used a gas-fired muffle for their experiments, the rate of oxidation would be higher than that in air, owing to the pollution of the atmosphere.

As the authors stated, there was no clear evidence in the literature that the oxidation rate of steel was affected by its carbon content, at least in the case of low-carbon steels in which they were particularly interested. The investigators who had studied the oxidation of ferrous metals had used electrolytic iron, ingot iron or mild steel, according to choice, as their basis material; when their experimental results were correlated, the composition of the material did not seem to have had any marked effect. It was certainly fair to conclude that the purer forms of iron, such as ingot iron, had no superiority over low-carbon steels in regard to resistance to straightforward oxidation in air or oxygen. Thus, to refer to Hatfield's work again, an iron containing 99·92% of iron, presumably an ingot iron, was attacked 5 times as much as a 0·17% carbon steel in oxygen at 500° C. and 17 times as much as the latter in steam at this temperature. Strangely enough, the ratio decreased in both cases with increasing temperature, until at 1000° C. the iron was the more resistant material. This supported the authors' conclusion that the corrosion of steel by molten nitrates was a different phenomenon from atmospheric oxidation, as was to be expected, since one reaction took place at a solid/liquid interface but the other at a solid/gas interface. Did the authors consider that there was any preferential attack on the pearlite by penetration along the grain boundaries which would account for the superior resistance of the ingot-iron pots as compared with mild-steel ones?

Mr. R. Chadwick (Birmingham) wrote that this paper was very welcome at the present time, for the scaling of salt-bath containers was still a serious problem to light-alloy manufacturers and users. The published literature on the subject had generally been marked by a good deal of random comment and suggestion with little fundamental investigation of the type now presented.

The writer's own laboratory had carried out a large amount of investigational work on the reactions occurring in molten sodium and potassium nitrates and on the corrosion of steels by these salts with various additions, including the decomposition products of the reactions. Much of that work had been of a similar nature to that of the authors, but in addition observations had been made on a large gas-fired bath holding some 15 tons of salt.

Armco iron was generally considered to offer resistance to

[1] W. H. Hatfield, *Journal of the Iron and Steel Institute*, 1927, No. I., p. 483.

corrosion superior to that of ordinary mild steels, and they there-
fore investigated the attack of nitrates on small steel pots of vary-
ing carbon content up to 0·5%. On the whole, the results from
such small-scale experiments were disappointing, for hardly any
corrosion of the type found in the large bath could be reproduced
under conditions in which they expected it to occur, nor could they
find any evidence of increased susceptibility in steels of high carbon
content.

The small-scale experiments alone would have entirely confirmed
one of the authors' main conclusions, namely, that local over-
heating did not in itself produce corrosion at that point. Observa-
tions on the large bath, however, showed that the majority of
corrosion patches were produced at the burner levels in the region
of maximum heating, as would be seen from the reproduction of a
typical map in Fig. A. The writer would therefore suggest the
qualified conclusion that whilst corrosion did not necessarily occur
in, nor was it entirely confined to, an overheated area, nevertheless
there was a strong tendency for the maximum corrosion to be
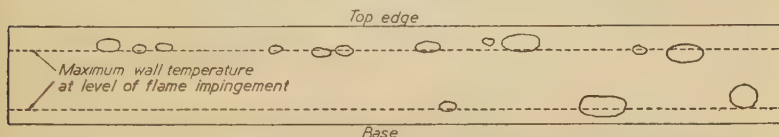
Fig. A.—Typical Distribution of Corrosion Patches on Wall of Mild-Steel
Salt Bath (length 26 ft.). Analysis: Carbon, 0·16%; silicon, 0·03%;
manganese, 0·68%; sulphur, 0·005%; phosphorus, 0·022%.

developed there. A probable explanation of these contradictory
results was that the commencement of corrosion took place at
susceptible points on the steel, and was independent of local heating
conditions, but that the rapid development of intense corrosion
only occurred at overheated points. If this was so, one might
reasonably expect that only in large baths would a sufficient
number of susceptible points coincide with overheated areas, and
so lead to rapid and severe attack.

Mr. S. N. BRAYSHAW (Manchester) wrote that everyone con-
cerned with molten nitrates was indebted to the authors of this
paper. The experimental work involved was enormous. It was
stated that the maximum variation amongst nine pots at 500° C.
for six weeks was not more than 7° C. To conduct a series of tests
demanding continuous runs, extending in one case to more than
nine weeks, was an arduous undertaking, and to maintain such
accurate temperature control meant that good facilities must have
been employed and that careful persistent attention was ungrudg-
ingly given. Ability, too, was shown in the clear presentation of
the results obtained.

He noticed that on p. 154 P mention was made of a pot which was heated for 3000 hr. at 500° C. This was more than four months of 24-hr. days. Could it be assumed that in this case the total time was broken by intervals and the test was not made with continuous running ?

Pots C.46 and C.49 showed external corrosion which appeared to be quite unaccountable. The faithfulness with which this was recorded was to be commended and gave all the more confidence in the various notes and observations. This abnormality was a warning, because unaccountable behaviour might have occurred internally as well as externally.

He would like to supplement what the authors had said about the advantage of a low melting point. He agreed that this was beneficial for intermittent work, but it was also of importance for continuous work. A low freezing point prolonged the period of fluidity and minimised the loss occasioned by the salt adhering to the work on withdrawal.

Pots C.48 and C.52 were both made of steel K, and both contained sodium nitrate with 0·3% of chlorine at a temperature of 500° C. for 500 hr.; the increases in weight were 42 g. and 17 g., respectively. There was no indication of any known factor to account for such a discrepancy.

Again a comparison might be made between pots all made of K steel, all containing sodium nitrate with 0·1% of chlorine, and all maintained at the same temperature of 500° C. Two of these pots (C.46 and C.50) showed, in 500 hr., an average increase in weight of $10\frac{1}{2}$ g., but two others (C.56 and C.60), which were treated for double time (1000 hr.), showed an average increase of only $8\frac{1}{2}$ g. Even if one forgave the pots for not showing double wastage in double time one could not feel that they revealed the whole truth when the wastage was actually lessened as the time was prolonged.

In this connection he noticed that Tables II., IV. and V. each gave particulars of the behaviour of nine pots, this being the full number for which the furnace was designed. In other cases there were fewer than nine pots and some numbers were missing. One would like to know whether all the results obtained had been included in the paper.

Much significance might attach to the time given for the first sign of corrosion. One wondered how the observations were made and how it was possible to say that corrosion first appeared after 12, 106 or 190 hr. Was there any stable relation between the first appearance of corrosion and the ultimate life of the pot ? Pots C.14 and C.15 were made of different steels; the first sign of corrosion was after 384 hr. in one case, and 24 hr. in the other, yet at the end of the test (1570 hr.) there was but little difference between them as shown by the increase in weight—12 and 15 g., respectively.

Again, pot C.73 showed the first sign of corrosion after 72 hr.,

and in 798 hr. the gain in weight was 9 g. Pot C.77 resisted visible corrosion for 106 hr., but in only 370 hr. the gain in weight was as much as 18 g. Both these pots were of steel K and there was no spraying. Was there any known treatment to account for the discordant results ?

With regard to local overheating, he agreed that failures occurred which were not caused in this way, but he knew also of many cases in which failure had arisen through this cause alone. He suggested that the paragraph on this subject should be reconsidered. These tests were made with 22-gauge (0·030 in.) steel pots containing 7 oz. of salt, and though they were heated on one side only the internal difference in temperature, levelled up by convection currents, would be slight. The pots were therefore not a good guide, in this respect, for what would happen in commercial installations.

Of very great interest to the writer was the final section on the reactions in the salt. This was a subject on which he had worked for a long time, and in 1913 he was granted a patent for a melt, known in the trade as " Quenchoid," consisting of nitrates and nitrites of potassium and sodium. In the patent specification he explained that it could be made by mixing the constituent salts or by mixing sodium nitrate and potassium nitrate and heating strongly.

It was wonderful what good work Carnelley did more than half a century ago. The writer made great use of that investigator's tables in his early work in which he conducted many experiments in fusible salts of many kinds. In the case of nitrates, one of the writer's methods was to heat samples of nitrates or mixtures of nitrates to predetermined temperatures for definite periods of time and then to take the freezing point on cooling. The same sample was heated and cooled repeatedly, and out of large numbers of records made in 1913 the following typical notes were extracted :

Sample consisting of 5 lb. of $NaNO_3$ + 5 lb. of KNO_3.

After heating for 15 min. to—	Freezing at—
$400°$ C.	$208°$ C.
$500°$ C.	$208°$ C.
$550°$ C.	$208°$ C.
$600°$ C.	$208°$ C.
$625°$ C.	$205°$ C.
$650°$ C.	$195°$ C.
$675°$ C.	$178°$ C.
$700°$ C.	$176°$ C.
$725°$ C.	$173°$ C.
$750°$ C.	$170°$ C.
$775°$ C.	$166°$ C.
$800°$ C.	$137°$ C.
$825°$ C.	$134°$ C.

The freezing points given above were probably low because of impurities in the nitrates, and also he was not necessarily working

with scientific accuracy; he was making a series of empirical experiments in the search for a " melt " with certain characteristics. He attributed the lowering of the melting point to the production of nitrites, and, from the loss in weight, he calculated the probable approximate composition of the residue. By differential freezing, and other means, he selected samples, from time to time, for analysis and so arrived at desirable mixtures for certain purposes.

He had heated nitrates until nitrogen peroxide rose in dense brown volumes, rolled down the sides of the furnace, and spread out on the floor, and he had continued his trials until a violent reaction swiftly melted the pot to a white heat. He had worked on many lines, including trials with a number of less usual salts such as nitrates of barium, strontium and lithium. He hoped the authors of this paper would be encouraged to continue and extend their investigations. The discordant results to which he had called attention could be explained if all the factors were known. An enormous amount of further work might be usefully directed to research in this one branch of fusible salt mixtures.

An outstanding point of commercial importance that emerged in the paper was the evil character of chlorides, which, however, according to Table VIII., might be countered by the use of nitrite. He specially noted the conclusion that a small percentage of nitrite was ineffective but that 15% was sufficient completely to neutralise so much as 0·5% of sodium chloride. One was rather chary of giving away trade secrets, but he might say that this figure was within a fraction of 1% of the nitrite content of his " Alumelt."

It must be remembered, of course, that this research dealt with the corrosion of steel containers, and it was valid in its own field. It still remained that the container was only a means to an end, and the aluminium under treatment was the main concern. With this in mind, it must be said that, whilst the evil effects of chlorine on the pot might be wholly or partly counteracted by the addition of nitrite, and whilst this was not the only reason for the addition of nitrite, it was still true that chlorides were injurious to aluminium alloys and their percentage should be kept at a minimum.

He did not think the evidence produced was sufficient to generalise about the nitrate-nitrite reaction. Hs was aware that clearly defined results could be obtained in the laboratory, but he did not know of any published work, even on a laboratory scale, which dealt adequately with the progressive changes, under constant oxygen pressure, in the nitrate-nitrite proportions at varying temperatures. The besetting difficulties in this connection were shown by pot C.76, which contained sodium nitrate to which 1·5% of nitrite had been added; the nitrite percentage of this pot after 370 hr. at 500° C. rose to 2·65% and yet in another pot the sodium nitrate after 3000 hr. at the same temperature contained only 0·4% of nitrite. These figures conflicted with one another and ran

counter to the remarks towards the end of the paper that in air and at 500° C. the equilibrium mixture of the sodium salts contained about 4% of nitrite.   The experimental work was inadequate to establish the position.   From his own experience he would say, with some qualifications, that given concentrations of nitrite could be readily produced by temperature treatments but that, on a commercial scale, the reverse action was slow and uncertain.

He concluded by expressing his appreciation of the paper and and cordial thanks to the authors.

AUTHORS' REPLY.

The AUTHORS replied that they were grateful to Mr. Ballard and Mr. Parker for pointing out the apparent misinterpretation of the significance of the quenching process in Rollaston's method of aluminising.   As it happened, other tests, not recorded in this paper, were done on aluminium-sprayed steels which had received commercial heat treatments, and these gave heavier corrosion than those treated in the laboratory.   It therefore seemed that the quenching operations did not cause much deterioration in the aluminium coating, and there was no reason to modify the conclusions stated in the paper.

Concerning the thickness of the aluminium coatings, pots $C.12$ and $C.19$ had a protective layer 0·004–0·006 in. thick, and pots CXC and $CX2$ 0·010–0·012 in. thick.

The suggestion that silica acted as a catalyst in the corrosion reaction was interesting.   The pure salts themselves contained no silica, and there was no analytical evidence that silica was present in the salts at the end of any of the tests.   It was, however, realised that ordinary analytical methods would not reveal the presence of traces of silica which could initiate a catalytic reaction, and this fact would be remembered in future investigations.

The possibility that slag inclusions in the steel might play an important part in the reaction was naturally considered, and there was, indeed, further evidence, not included in the paper, which also pointed in this direction.   The evidence bearing on the significance of the composition of the steel was, however, inconclusive, and the authors had therefore refrained from enlarging on this aspect of the problem, which was still under investigation.   It was hoped that it might be possible to deal with some of the outstanding points in a later communication.

The negative results quoted by Mr. Chadwick in small-scale tests were surprising, but in view of the absence of any detailed information on the method of test used it was not possible to offer any useful comment.   As to the question of the localisation of corrosion in overheated zones, there was nothing contradictory in the result quoted by Mr. Chadwick, and the authors were entirely

in agreement with the view that overheating would stimulate this form of corrosion, once it was initiated.

In reply to Mr. Brayshaw, the authors must first deal with his comment " one would like to know whether all the results obtained had been included in the paper." It was hardly necessary to explain here that in an investigation of this kind there were inevitably many exploratory tests, for instance, on the effect of added impurities, which gave negative results and obviously did not merit publication. Hence the gaps in the numbers. Mr. Brayshaw also pointed out that certain repeat experiments failed to give identical results in terms of the final increase in weight and that the rate of corrosion seemed to vary in an irregular fashion with time. The authors were at pains to point out in the paper that too great a significance should not be attached to the numerical value of the weight increase, which was bound to show irregular variations in view of the heterogeneous nature of the experimental material and the localised form of the corrosion.

With regard to the validity of the small-scale test on the effect of local overheating, the authors pointed out that as long as the pot remained scale-free the temperature gradient through the metal wall would remain small, so that the thickness of the metal was entirely irrelevant. It was, however, agreed that with thoroughly ill-designed salt baths—and such were unfortunately not unknown —local overheating might be a factor of the first importance.

Finally, Mr. Brayshaw's comments on the authors' conclusions regarding the nitrate-nitrite equilibrium appeared to be based on a misreading of these conclusions, since no attempt was made to give a precise statement of the equilibrium concentrations. In view of the slowness with which the reaction sometimes proceeded, as in the case of the 3000-hr. test, and of the complex nature of the reactions at the metal surface, such an attempt would obviously be premature.

AN ACCELERATED SPRAY TEST FOR THE DETERMINATION OF THE RELATIVE AT-MOSPHERIC CORRODIBILITY OF FERROUS MATERIALS.*

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(Figs. 1 and 2 = Plate IX.)

Paper No. 2/1940 of the Corrosion Committee (submitted by the Laboratory Research Sub-Committee).

Summary.

The development of a method of automatic accelerated spray testing is described, in which the specimens, on an endless belt, complete a cycle of treatment, consisting of spraying, followed by drying in air and in a warm chamber. The cycle is completed in 7 min. and the specimens are subjected to 60 cycles per day. A standardised douching with water is given at the commencement of the second and subsequent days and the daily spraying and drying treatment is carried on for 20 days. Comparative results of long-period field tests and spray tests are given for 14 irons and steels of the low-alloy constructional type. Good agreement is shown in the orders of merit obtained in one-year field tests and in the 20-day spray tests, using a spray liquid consisting of $N/100$ sulphuric acid and $N/100$ sodium chloride. Less satisfactory agreement is shown in field tests and spray tests using $N/100$ and $N/20$ sulphuric acid. It is suggested that the results obtained with the sulphuric-acid/sodium-chloride solution are of sufficient promise to encourage other workers to re-examine the spray method as the basis of a satisfactory short-time laboratory corrosion test.

THE desirability of having a reliable laboratory method for the rapid evaluation of the relative atmospheric corrodibility of irons and low-alloy steels of the constructional type has long been considered by many workers in the field of corrosion research. The position in regard to relative corrodibility under conditions of immersion has been clarified by the excellent work by Bengough and Wormwell.[1] It is generally accepted, however, that immersion tests do not produce the same order of merit as is obtained in long-period exposure to the atmosphere.

The conditions of atmospheric corrosion entail the wetting of steel by weakly acid liquids (particularly in industrial atmospheres) and subsequent evaporation of the liquids; condensation of liquids and evaporation, with changes of temperature; partial removal by

mechanical means of the corrosion product, and so on. The obvious experimental procedure is suggested, therefore, of attempting to reproduce in the laboratory a cycle of atmospheric changes involving wetting and drying, heating and cooling, in which the corrosion is of the oxygen-absorption type. From the wide differences in results obtained by atmospheric exposure and by immersion in acid, the authors consider that hydrogen evolution plays no major part in atmospheric corrosion. Since the supply of oxygen will be facilitated if the corrosive medium is in the form of fine droplets, it is desirable to wet the specimens with a fine spray. Also, as the size of the droplets decreases, it should be possible to increase the acidity of the solution without unduly introducing the effect of hydrogen evolution. This is in line with the views of Evans.[2]

Earlier work on spray tests had been carried out by Evans and Britton,[3] Hatfield and Shirley,[4, 5] Hudson [6] and Schroeder.[7] Using a simple spraying procedure, twice a day for 23 days, Evans and Britton [3] concluded that it seemed possible to obtain, in laboratory spray tests, an order of merit which was a reliable indicator of the " liability to *commence* rusting " under typical service conditions. They suggested $N/100$ sulphuric acid as the spray liquid for urban atmospheres and either sea water or $3 \cdot 5\%$ sodium chloride solution for marine atmospheres. They also stated the view that the order of merit for long-time atmospheric exposure was unlikely to be the same as that obtained in short-time laboratory spray tests, at the same time indicating the possibility that more intensive spraying with acid, of the order of 10 times daily with intervening drying periods, might within a reasonable time reveal the long-period order. Hatfield and Shirley [4] sprayed their specimens at constant spray pressure, once daily for 36 days, using two different types of spray liquid, (a) 3% sodium chloride solution and (b) $N/100$ sulphuric acid. Their results showed that some materials in the salt-spray tests corresponded quite well with the short-time field tests, whilst other materials were not so good ; the agreement of the acid tests with the short-time field tests was less satisfactory than that for the salt-spray tests. Hatfield and Shirley [5] supplemented their work with one-year field tests. They found good agreement between the salt-spray and the short-time (36-day) field tests for the more resistant steels, but the less resistant steels (of the type dealt with in the present paper) gave different results. For these steels better correspondence was found between the salt-spray and the long-time (one-year) field tests, but anomalies existed. For instance, the salt-spray tests failed to bring out the beneficial effect of $0 \cdot 45\%$ of copper in mild steel. The acid-spray tests did show this, but, on the other hand, the general correspondence between the acid-spray and the field tests was still less satisfactory. Hudson [6] used a fixed spray device and sprayed his specimens twice daily with $N/100$ sulphuric acid for 20 days. The correlation between Hudson's spray tests and short-time field

tests supported the view of Evans and Britton [3] that the inter-
mittent spray test gives the short-period order of merit of the
materials tested. Hudson also commented on the fact that better
agreement between the two types of test was obtained in the case
of ground specimens than of pickled ones, suggesting that this was
possibly due to the behaviour of the copper in the copper-bearing
steels during pickling.

Schroeder's [7] work is of especial interest, as he rendered the
spraying automatic, by mounting the specimens on a belt, driven
by motor and reduction gearing, thereby bringing the specimens,
at fixed intervals, into the operation zone of the sprays. The
first spray apparatus constructed at Stocksbridge (described below)
actually contained a few of the parts of Schroeder's equipment.
Schroeder used sprays consisting of (a) $N/100$ sulphuric acid and
(b) a mixed-salt solution containing 16 g. of ammonium sulphate
and 4 g. of ammonium chloride per litre, and he also describes
one test in which, in addition to spraying, downpour and sunshine
were simulated, by douching the specimens periodically with
water, followed by exposure to a heating element. In this test he
obtained accelerated corrosion, as compared with tests when
spraying only was carried out, and also a marked improvement
in correlation with the short-period field test.

A further effort to correlate spray tests with field tests was
made by Hatfield and Shirley, Swinden and Stevenson, and Hudson
and Banfield,[8] who carried out spray tests at Sheffield, Stocks-
bridge and Birmingham, and exposure tests at Sheffield and Stocks-
bridge, on 8 low-alloy structural steels in connection with Part III.
of the Corrosion Committee's experimental programme. Two
types of spray liquid were used, $N/100$ sulphuric acid and the
mixed-salt solution previously used by Schroeder (vide supra).
Comparing the spray-test results with short-period (4-week) and
long-period (one-year) field tests, no correlation was found between
the results of the intermittent spray tests with the mixed-salt
solution and either series of field tests ; the spray tests with $N/100$
sulphuric acid were only slightly more satisfactory. Excellent
agreement was found in the different series of long-period field
tests, but there was no satisfactory correlation between the different
laboratories, either in the spray tests or in the short-period field
tests. The results of the short-period field tests agreed better
with the long-period field tests than did the results of either series
of spray tests. In this investigation the spray method in each of
the three laboratories was of the static type previously investigated
by Hatfield and Shirley [4, 5] and by Hudson.[6]

As stated in the Fifth Report of the Corrosion Committee,[9]
the authors proceeded to modify and extend Schroeder's automatic
spraying apparatus, so that larger specimens, 4×2 in., could be
accommodated. All operations were standardised as far as possible,
in an effort to ensure equal treatment for all specimens. The

principles observed were those of Schroeder's douching test in that the cycle of operations consisted of intermittent spraying, followed by exposure to a heating chamber; also, the specimens were given a daily douching with water, under standardised conditions, for the purpose of detaching loose rust from the surface.

The Test Materials.

For the spray tests, a series of 14 Corrosion Committee materials was selected, 11 of which had been the subject of previous field tests (and, in the case of 7 materials, previous spray tests [8]) and 3 of which were new materials—Aston-Byers iron, Swedish iron and carbonyl iron. The analyses of the materials are given in Table I.

TABLE I.—*Analyses of the Steels and Irons Tested.*

Material.	C. %.	Mn. %.	Si. %.	S. %.	P. %.	Cr. %.	Cu. %.
Carbonyl iron . .	0·02	Nil	Trace	Nil	Nil	Nil	Trace
Swedish Lancashire iron . . .	0·03	Nil	0·02	0·008	0·054	Nil	Trace
Staffordshire wrought iron . . .	0·03	0·02	0·14	0·019	0·23	Trace	0·04
Aston-Byers iron .	0·02	0·02	0·12	0·007	0·14	Trace	Trace
Ingot iron . . .	0·03	0·03	0·03	0·036	0·009	Nil	0·04
Rail steel . . .	0·53	0·72	0·30	0·037	0·043	Nil	0·01₅
XK steel . . .	0·21	0·58	0·10	0·032	0·042	0·09	0·02
ZK steel . . .	0·23	0·60	0·11	0·026	0·035	0·06	0·50
K steel . . .	0·27	0·59	0·12	0·031	0·042	0·98	0·02
L steel . . .	0·26	0·60	0·13	0·026	0·038	0·59	0·47
N steel . . .	0·28	0·83	0·13	0·038	0·043	0·92	0·47
O steel . . .	0·24	1·53	0·34	0·035	0·036	0·03	0·52
X2 steel . . .	0·23	0·59	0·01	0·026	0·031	0·06	0·02
Z steel . . .	0·21	0·62	0·03	0·036	0·039	Nil	0·52

In all the spray tests and field tests the results of which are given in this paper, specimens approximately $4 \times 2 \times \frac{1}{8}$ in. (weighing approximately 125 g.) were used, with their surface ground on a linisher belt, grade 80.

The Apparatus and Method.

The equipment used for the spray tests has undergone a slow process of evolution in the laboratory and it is therefore desirable to give detailed descriptions both of the original form and of the latest form now in use. The original apparatus is shown in Fig. 1 and its operation is described as follows :

The specimens (maximum number 20, of size 4×2 in.) are attached to a travelling belt by means of short lengths of cord passing through holes in the specimens and hanging from hooks on the belt. The latter moves round the 12-in. dia. pulleys A,

PLATE IX.

Fig. 1.—The Original Apparatus for Accelerated Spray Tests.
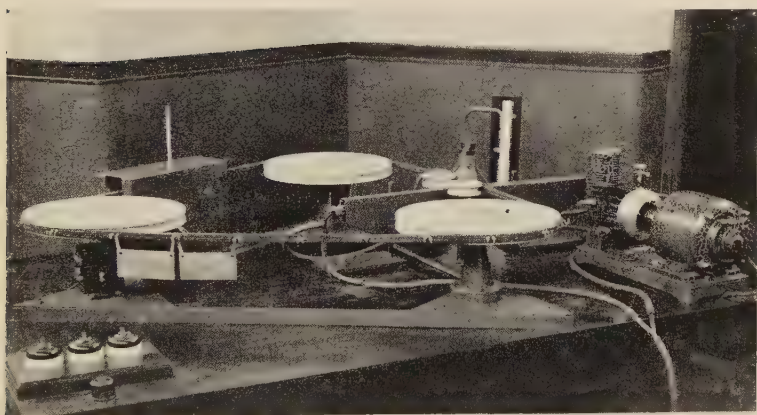
Fig. 2.—The New Equipment for Accelerated Spray Tests.

B and C. The pulley A has a belt-drive from the motor M and reduction gearing RG.

The belt on which the specimens are hung moves round the three pulleys at a speed of one complete revolution per 7 min., and during each revolution the specimens are subjected to the following treatments :

Spraying.

Passing between the spray-shields, S, S', they are sprayed on both sides with the spray solution. This spray is obtained by means of compressed air (from a blower) passing from the gas reservoir G to the two solution reservoirs, R, R'. The latter are Winchester quart bottles fitted with bakelite spray nozzles capable of delivering a uniform spray at a distance of 12 in. from the nozzle. The compressed-air pressure is measured by the mano-meter P, and is gradually increased as the level of the solution in the spray reservoirs falls. Spray is allowed to impinge on the specimens over only $\frac{1}{2}$ in. of their length at a given moment (*i.e.*, the specimens are sprayed for a period of about 2 sec.). Liquid not impinging on a specimen falls into the sump O or into the sumps of the spray shields, S, S', whence it is drained into O.

Drying.

After spraying, the specimens pass round the pulleys C and A, during which time they are air-dried to some extent, after which they pass through the heated chamber H. This is a metal box, ventilated at the top and bottom and heated by means of two carbon-filament lamps working at a voltage which will raise the temperature of the air passing through the chamber to 40° C. In passing through this chamber, during a period of about $\frac{3}{4}$ min., the specimens become quite dry on the surface but are not heated unduly.

After passing through the heating chamber, the specimens travel round the pulley B back to the sprays and so on.

Douching.

The specimens pass through the cycle of treatments 60 times per day (approximately 7 hr.), 5 days per week for 4 weeks. On the second and subsequent days they are douched with distilled water and allowed to dry thoroughly before spraying is commenced.

The daily douching is carried out by a standardised procedure : Distilled water (110 ml.) is placed in a tap funnel and is allowed to run, with an initial pressure of 14 in. of water, on to one surface of the specimen. The water emerges from a jet which allows the tap funnel to run dry in 22 sec. The jet is moved by hand over the surface of the specimen and about 1 in. from it. The move-ment of the point of impingement on the surface of the specimen is in a clockwise direction and 6 complete circles are described

during the douching. The method of douching is illustrated in
Fig. 3.

Weighing.

The corrosion of the specimens is measured in terms of loss in
weight per unit area after the removal of the corrosion products
by means of Clarke's solution.*

Using the foregoing equipment and *modus operandi*, two sets
of spray tests on the 14 materials were carried out, spraying with
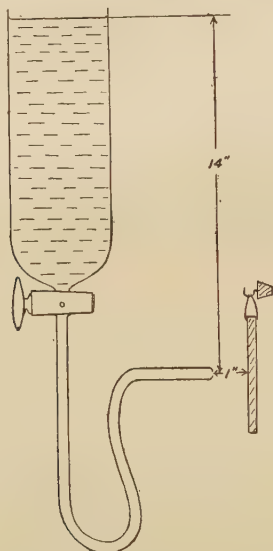
Fig. 3.—Method of Douching Specimens.

$N/100$ sulphuric acid. Notes on the appearance of the specimens
during the two sets of tests are given in the Appendix. The ex-
perimental details and results of the tests are recorded in Table II.

Progress of the Tests and Modifications in the Apparatus.

During the tests on $N/100$ sulphuric-acid spray, difficulty was
experienced in maintaining a constant spray volume of equal
intensity on the two faces of the specimens. This was due to the
level of liquid in the spray bottles falling at slightly different rates
during a day's run. The apparatus was therefore modified as
follows : Instead of using bottles of spray liquid and adjusting the

* S. G. Clarke's de-rusting solution : Hydrochloric acid (100 parts) con-
taining antimonious oxide (2 parts) and stannous chloride (5 parts).

TABLE II.—*Results of First Series of Spray Tests using* N/100
Sulphuric Acid.

Spraying carried out for 20 days, 60 cycles per day.

Material.	Mean Loss of Weight per Standard Specimen.* G.		Loss in Weight Referred to Steel X2 as 100.		
	First Test.	Second Test.	First Test.	Second Test.	Mean.
Carbonyl iron	0·701	0·522	86	100	93
Swedish Lancashire iron	0·873	0·598	107	114	110·5
Staffordshire wrought iron	0·851	0·570	104	109	106·5
Aston-Byers iron	0·950	0·608	116	116	116
Ingot iron	0·838	0·559	102	107	104·5
Rail steel	0·886	0·519	108	99	103·5
XK (0·2% C, solid)	0·849	0·495	104	95	99·5
ZK (0·2% C, 0·5% Cu, solid)	0·818	0·491	100	94	97
K (1% Cr)	0·826	0·488	101	93	97
L (0·6% C, 0·5% Cu)	0·752	0·509	92	97	94·5
N (1% Cr, 0·5% Cu)	0·778	0·477	95	91	93
O (0·5% Cu, 1·5% Mn)	0·829	0·476	101	91	96
$X2$ (0·2% C, balanced)	0·817	0·523	100	100	100
Z (0·2% C, 0·5% Cu, balanced)	0·803	0·490	98	93	95·5

* Total area of standard specimen, 16 sq. in.
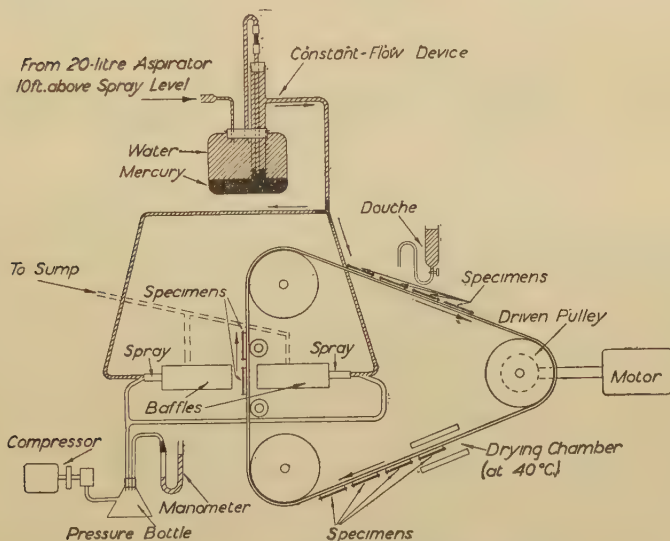
FIG. 4.—Diagram Showing the Principles of the New Spray Apparatus.

spray pressure periodically, a large aspirator full of liquid is placed 10 ft. above the level of the spray apparatus. The spray liquid is passed from the aspirator through a device (shown in Fig. 4) which ensures a constant flow of liquid, independent of either the hydrostatic pressure or the back pressure of the air blast. After passing through this device, the stream of liquid is split into two equal streams, each passing through a length of fine capillary tubing and thence to the spray nozzles. The spray liquid is converted into a fine nebula by the air blast, which is kept constant at a definite pressure.

Two additional duplicate sets of tests on the 14 materials were carried out on the spray apparatus modified as above, using (a) $N/20$ sulphuric acid and (b) a mixed solution containing equal proportions of $N/50$ sulphuric acid and $N/50$ sodium chloride, *i.e.*, centinormal in respect to each constituent. Observations on the progress of the spray tests are given in the Appendix, and the results of both series of tests are given in Table III. The two sets of spray tests using the mixed solution were controlled at

TABLE III.—*Results of the Second Series of Spray Tests using* (a) $N/20$ *Sulphuric Acid, and* (b) *a Solution of* $N/100$ *Sulphuric Acid,* $N/100$ *Sodium Chloride.*

Spraying carried out for 20 days, 60 cycles per day.

Material.	$N/20$ Sulphuric Acid.					Mixed Solution ($N/100$ Sulphuric Acid, $N/100$ Sodium Chloride).†				
	Mean Loss of Weight per Standard Specimen.* G.		Loss in Weight Referred to Steel $X2$ as 100.			Mean Loss of Weight per Standard Specimen.* G.		Loss in Weight Referred to Steel $X2$ as 100.		
	First Test.	Second Test.	First Test.	Second Test.	Mean.	First Test.	Second Test.	First Test.	Second Test.	Mean.
Carbonyl iron	0·628	0·860	100·5	102	101	0·752	1·784	158	133	145·5
Swedish Lancashire iron	0·679	0·937	109	111	110	0·771	2·106	162	156·5	159
Staffordshire wrought iron	0·598	0·832	95·5	99	97	0·476	1·216	100	91	95·5
Aston-Byers iron	0·693	0·947	111	112	111·5	0·662	1·711	138	127	132·5
Ingot iron	0·628	0·890	100·5	106	103	0·575	1·520	115	113	114
Rail steel	0·631	0·890	101	106	103·5	0·462	1·266	97	90	93·5
XK (0·2% C, solid)	0·628	0·826	100·5	98·5	99·5	0·460	1·323	97	99	98
ZK (0·2% C, 0·5% Cu, solid)	0·581	0·783	93	93	93	0·415	1·186	87	88	87·5
K (1% Cr)	0·603	0·767	96·5	91	93·5	0·420	1·293	88	96	92
L (0·6% Cr, 0·5% Cu)	0·584	0·747	93·5	89	91	0·413	1·121	87	83	85
N (1% Cr, 0·5% Cu)	0·551	0·724	88	86	87	0·387	1·116	81	82	81·5
O (0·5% Cu, 1·5% Mn)	0·581	0·749	93	89	91	0·437	1·138	92	85	88·5
$X2$ (0·2% C, balanced)	0·625	0·841	100	100	100	0·476	1·346	100	100	100
Z (0·2% C, 0·5% Cu, balanced)	0·590	0·791	94·5	94	94	0·428	1·251	90	92	91

* Total area of standard specimen, 16 sq. in.
† Two sets of tests operated at different spray intensities.

different spray intensities, and this is reflected in the loss-of-weight figures. It is seen that the volume of spray liquid falling on the surface of the specimens does not affect materially the order of merit obtained. It should be noted, however, that in all cases the volume of spray was so controlled that the droplets impinging on the specimens did not completely wet the surfaces. This is discussed later. Duplicate field tests were also carried out for one year in the semi-industrial atmosphere at Stocksbridge (7 of the materials had been the subject of previous one-year field tests at Stocksbridge [8]). Observations on the progress of the corrosion are given in the Appendix, and the results are listed in Table IV.

TABLE IV.—*Results of Field Tests carried out at Stocksbridge.*
27/7/37 to 27/7/38.

Material.	Mean Loss of Weight per Standard Specimen.* G.			Loss in Weight Referred to Steel $X2$ as 100.
	A.	B.	Mean.	
Carbonyl iron	9·86	9·23	9·54	126
Swedish Lancashire iron	9·61	9·94	9·77	129
Staffordshire wrought iron	7·49	6·96	7·22	95·5
Aston-Byers iron	8·58	8·28	8·43	111
Ingot iron	8·14	8·25	8·19	108
Rail steel	6·89	6·89	6·89	91
XK (0·2% C, solid)	6·59	6·99	6·79	90
ZK (0·2% C, 0·5% Cu, solid)	5·85	5·70	5·77	76
K (1% Cr)	6·45	6·30	6·37	84
L (0·6% Cr, 0·5% Cu)	5·46	5·43	5·44	72
N (1% Cr, 0·5% Cu)	5·00	4·98	4·99	66
O (0·5% Cu, 1·5% Mn)	5·88	5·91	5·89	78
$X2$ (0·2% C, balanced)	7·64	7·50	7·57	100
Z (0·2% C, 0·5% Cu, balanced)	6·19	6·33	6·26	83

* Total area of standard specimen, 16 sq. in.

As a result of the good agreement, discussed later, between the long-period field tests and the sulphuric-acid/sodium-chloride spray tests, it was decided to build an entirely new equipment. This is shown in the photograph, Fig. 2, and incorporates additional improvements, in that a direct drive through the gear box is used instead of a belt drive, and the apparatus has greater stability, achieved by lowering the travelling belt and using metal and Sindanyo parts, instead of wood. Also, the carbon-filament heater lamps were replaced by a strip heater covered by a sheet of stainless steel. This was necessary to accommodate the drying section of the apparatus in the new layout and had the added advantage that the thermometer was not directly exposed to radiation from the carbon-filament lamps. Fig. 4 shows the entire equipment diagrammatically. The results obtained for duplicate tests on

13 materials, using the new equipment, are given in Table V. Observations of the progress of the corrosion were made, but have not been included, as they bore such great similarity to the observations recorded in the Appendix in connection with the earlier spray tests using the mixed sulphuric-acid/sodium-chloride solution. For the tests reported in Table V. the spray volume was controlled to give the maximum wetting of the specimens consistent with maintaining the individuality of the droplets on the surface of the specimens. For the purpose of judging droplet size, a stainless-steel control specimen was incorporated in each series of tests. Since this specimen does not corrode, it is possible to judge the spray volume with greater accuracy, as compared with the spraying of a surface coated with hydrated oxide.

TABLE V.—*Results of the Third Series of Tests using the New Spray Equipment and Spraying with a Solution of* N/100 *Sulphuric Acid,* N/100 *Sodium Chloride.*

Spraying carried out for 20 days, 60 cycles per day.

Material.	Mean Loss of Weight per Standard Specimen.* G.		Loss in Weight Referred to Steel X2 as 100.		
	First Test.	Second Test.	First Test.	Second Test.	Mean.
Swedish Lancashire iron . .	2·40	2·51	170	141	155·5
Staffordshire wrought iron .	1·53	1·82	109	102	105·5
Aston-Byers iron . . .	1·92	2·42	136	136	136
Ingot iron	1·74	2·51	123	141	132
Rail steel	1·38	1·74	98	98	98
XK (0·2% C, solid) .	1·43	1·84	101	103	102
ZK (0·2% C, 0·5% Cu, solid) .	1·32	1·66	94	93	93·5
K (1% Cr)	1·35	1·67	96	94	95
L (0·6% Cr, 0·5% Cu) .	1·20	1·53	85	86	85·5
N (1% Cr, 0·5% Cu) .	1·18	1·42	84	80	82
O (0·5% Cu, 1·5% Mn) .	1·29	1·74	91	98	94·5
X2 (0·2% C, balanced) .	1·41	1·78	100	100	100
Z (0·2% C, 0·5% Cu, balanced)	1·25	1·61	89	90	89·5

* Total area of standard specimen, 16 sq. in.

The orders of merit for the 14 materials in the field tests and the three types of spray tests are given in Table VI., whilst Table VII. shows the orders of merit for 7 steels which have been the subject of two long-period field tests at Stocksbridge and three types of spray test.

Consideration of the Results.

In the first set of spray tests, using N/100 sulphuric acid, the orders of merit for certain materials were in reasonably good agreement with the field-test results, but the " spread " of the

TABLE VI.—*Orders of Merit for 14 Steels and Irons in Field Tests and Three Types of Spray Tests at Stocksbridge.*

Material.	Field Tests. 27/7/37 to 27/7/38.	Spray Tests.			
		N/100 Sulphuric Acid, N/100 Sodium Chloride.		N/100 Sulphuric Acid.	N/20 Sulphuric Acid.
		Old Equipment.	New Equipment.		
Carbonyl iron	13	13	...*	1	10
Swedish Lancashire iron	14	14	13	13	13
Staffordshire wrought iron	9	8	10	12	7
Aston-Byers iron	12	12	12	14	14
Ingot iron	11	11	11	11	11
Rail steel	8	7	7	10	12
XK (0·2% C, solid)	7	9	9	8	8
ZK (0·2% C, 0·5% Cu, solid)	3	3	4	6	4
K (1% Cr)	6	6	6	6	5
L (0·6% Cr, 0·5% Cu)	2	2	2	3	2
N (1% Cr, 0·5% Cu)	1	1	1	1	1
O (0·5% Cu, 1·5% Mn)	4	4	5	5	2
$X2$ (0·2% C, balanced)	10	10	8	9	9
Z (0·2% C, 0·5% Cu, balanced)	5	5	3	4	6

* Carbonyl iron was not tested in this series.

TABLE VII.—*Orders of Merit for 7 Steels in Two Series of Field Tests and Three Types of Spray Tests at Stocksbridge.*

Material.	Field Tests.		Spray Tests.			
	A. 12/6/35 to 11/6/36.	B. 27/7/37 to 27/7/38.	N/100 Sulphuric Acid, N/100 Sodium Chloride.		N/100 Sulphuric Acid.	N/20 Sulphuric Acid.
			Old Equipment.	New Equipment.		
XK (0·2% C, solid)	6	6	6	7	6	6
ZK (0·2% C, 0·5% Cu, solid)	3	3	3	3	4	4
K (1% Cr)	5	5	5	5	4	5
L (0·6% Cr, 0·5% Cu)	2	2	2	2	2	2
N (1% Cr, 0·5% Cu)	1	1	1	1	1	1
O (0·5% Cu, 1·5% Mn)	3	4	4	4	3	2
$X2$ (0·2% C, balanced)	7	7	7	6	7	7

results was of a very low order. In fact, of 28 tests carried out on 14 materials, the highest and lowest loss-of-weight results (referred to the standard steel $X2$ as 100) were 116 and 86, respectively, the 86 result being an isolated figure, the next lowest being 91. For the second series of spray tests, therefore, an attempt was made to increase the relative corrosion of the materials. Two methods were adopted, *viz.*, (*a*) increasing the acidity and (*b*) introducing a second acid radical in the form of a salt addition.

The results in Table III. show that method (*a*) had no appreciable effect on the " spread " of the results ; the increased acidity of the solution caused acid attack, with sulphate formation and deposition on the specimens, and, apart from the relatively poor order of merit revealed, could not be regarded as an improvement on the $N/100$ sulphuric acid solution used for the first series of tests. On the other hand, the mixed sulphuric-acid/sodium-chloride solution increased the " spread " of the results materially—the maximum and minimum of the first set being 162 and 81, respectively—at the same time giving orders of merit very close to those of the one-year field tests. The actual loss-of-weight figures for the first set, however, were considered to be on the low side, with the result that a definite increase was made in the volume of spray used, and a decrease in droplet size, for the duplicate tests with the mixed liquid. The corrosion rate was thus increased by two to three times that of the first set and a fairly wide " spread " was also obtained—maximum 156·5, minimum 82. The agreement of the second set with one-year field tests, with respect to orders of merit, was quite good, as in the first set. It should be noted in the Tables that the mean of the loss-of-weight figures (referred to steel $X2$ as 100) has been taken to obtain the reported orders of merit for all the tests.

The tests carried out on the new equipment were virtually made under the same experimental conditions as those used for the second set of sulphuric-acid/sodium-chloride spray tests. The results of the new-equipment tests are given in Table V. and similar observations may be made in regard to them. The actual loss of weight is reasonably high—from 1·18 to 2·51 g. on 125-g. specimens—the " spread " of the results is quite good and the orders of merit for 13 materials are reasonably close to those obtained in one year's atmospheric exposure.

Conclusion.

In the view of the authors, the accelerated spray test described is of sufficient promise to be regarded as the basis of a laboratory method for the determination of the relative corrodibility of irons and constructional steels. In order to obtain reliable results by this method, certain experimental conditions should be adhered to, as postulated below ;

(1) Visible acid attack should not occur. Acid attack was obtained with $N/20$ sulphuric acid but not with $N/100$ acid under the conditions prevailing in the authors' experiments. Hence the maximum permissible acid concentration is at some stage between these two limits.

(2) The spray should consist of very fine droplets, each droplet being surrounded by air.

(3) The stainless-steel control specimen should not be *completely* wetted. This is determined experimentally by the size and intensity of the sprays, and the time taken in passing the sprays. This affords a ready means of avoiding excess spray liquid on the specimens, which would reduce the rate of oxygen supply to them.

The results have been placed on record for the main purpose of encouraging other workers in this field, who may consider it worth while to pursue the method with other spray solutions, or may introduce other modifications for the additional improvement of the method. It is well known that the relative corrodibility of ferrous materials differs in different types of atmosphere, and it is thereby feasible that a spray solution which gives the Stocksbridge or Sheffield order of merit may not be suitable for reproducing the order of merit obtained in urban or marine atmospheres. Further research in this direction is necessary.

Acknowledgments.

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APPENDIX.—*Summary of Observations on the Progress of the Tests.*

First Series of Spray Tests Sprayed with N/100 *Sulphuric Acid.*—
All specimens except carbonyl iron completely rusted to lighter
brown in one day.   Carbonyl iron completely rusted in four days.
During the course of the test the rust on all specimens became
progressively darker and thicker.   Steel *O* had the darkest-coloured
rust and the irons were somewhat lighter and more red than the
steel specimens, which were generally dark brown in colour.

Second Series of Spray Tests Sprayed with N/20 *Sulphuric
Acid.*—All specimens completely rusted to dark purplish brown in
one day.   During the course of the test the rust on all specimens
became progressively darker and thicker, finishing much darker in
colour than that produced by atmospheric corrosion at Stocks-
bridge.   There was definite evidence of sulphate on the surfaces
of all the specimens from an early stage in the tests.

Second Series of Spray Tests Sprayed with N/100 *Sulphuric
Acid,* N/100 *Sodium Chloride.*—All specimens except carbonyl iron
completely rusted to light brown after two days; carbonyl iron
rusted completely in three days.   During the course of the test
all materials progressively darkened and finished dark brown in
colour.   The second set of specimens had much coarser rust than
the first set owing to the increased spray volume.

Atmospheric Exposure for One Year Facing North and South.—
All specimens rusted to red-rust colour in one day, owing to the
action of dew.   During dry periods the rust became lighter in
colour and there was a tendency for the south face to be slightly
lighter than the north.   During the course of the test the rust
became gradually darker in colour, and from time to time patches
of thick rust were shed.   At the end of the test all the specimens
were dark brown in colour, the irons being slightly lighter and
steels *K, L* and *N* being slightly darker than the remainder.

DISCUSSION.

Mr. R. C. TUCKER (Sheffield) said that the paper described a very great step forward in the laboratory study of corrosion problems. His experience in studying such problems was that accelerated tests were very dangerous, but the one dealt with in this paper certainly seemed to give the right order of merit for industrial atmospheres, and he quite appreciated Dr. Swinden's concluding remarks, in which he disclaimed any comparison with conditions other than those which had actually been studied. That was, of course, a question for the future.

The series of steels dealt with had been allocated an order of merit on their loss of weight for both exposure and laboratory tests, and he would like to ask whether the degree of pitting was noticed on both tests, as this was most important. In fact, the main difference between mild steel and wrought iron was that steel failed dangerously at pits while wrought iron lost about the same weight uniformly over the whole of the exposed area.

Dr. J. C. HUDSON (Birmingham) said that in his view the results given by the authors were the most satisfactory that had yet been published in connection with accelerated tests on the resistance of ferrous metals to atmospheric corrosion. Although the authors' spray tests did not exactly reproduce the percentage corrodibilities of the different materials examined as observed in the field—a point to which he would return later—they did classify them accurately into categories, e.g., they showed that copper steels as a class were superior to ordinary steels and that copper-chromium steels were superior to copper steels, whilst some of the other materials, such as Swedish iron and carbonyl iron, had a relatively feeble resistance to corrosion. Thus the Laboratory Research Sub-Committee might justly claim to have achieved good progress in developing methods of accelerated corrosion testing. Indeed, it was of interest to note that the method of testing described in the present paper was being incorporated in a British Standard Institution specification for various types of protective coating.

It might be of value if he were to add a few comments on the general relationship between the results of accelerated laboratory tests and of field tests. The authors had naturally correlated their laboratory results with those of field tests conducted on the roof of their laboratory at Stocksbridge; they had observed that the quantitative relationship—i.e., the correlation obtained when both sets of results were expressed in terms of the corrosion of a standard material—was not exact and had pointed out that the relative corrodibilities of ferrous materials differed in different types of atmosphere. He would like to develop this last point a little. In conjunction with the second series of tests at Stocksbridge referred to in Tables III. and IV., two other series of field tests on similar

sets of specimens had been made by Dr. W. H. Hatfield, F.R.S., and Mr. H. T. Shirley on the roof of the Brown-Firth Research Laboratories and by Dr. T. A. Banfield and himself in the marine atmosphere of the Corrosion Committee's exposure station at Calshot. Both tests had been for the period of one year, as at Stocksbridge. The results would be discussed more fully in the next Report of the Laboratory Research Sub-Committee, but they might usefully be alluded to now, as supplementing the data given by the authors.
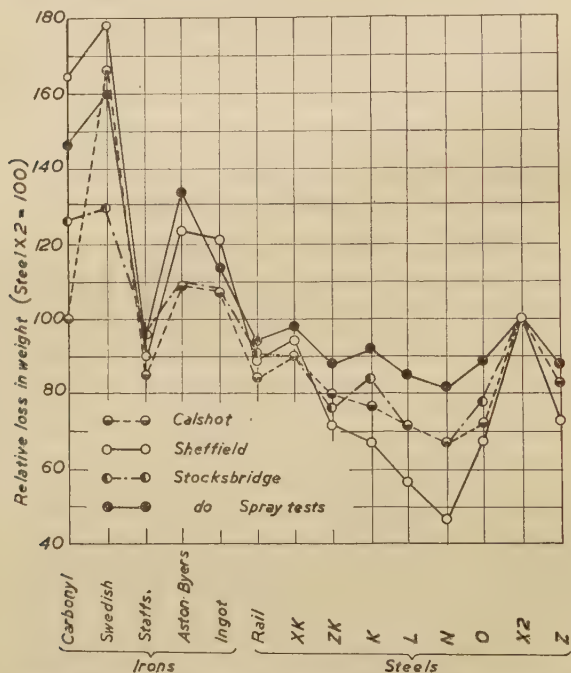
FIG. A.—Correlation of Field Tests and Intermittent Spray Tests.

Fig. A was a composite graph of the results of the three series of field tests at Sheffield, Calshot and Stocksbridge, respectively, and of those of the authors' second series of spray tests with a mixed sulphuric acid and sodium chloride solution. It would be seen immediately that all four curves belonged to the same family, or, in other words, that the spray tests reproduced the order of corrodibility of the materials tested as faithfully as that order was reproducible from one corrosion station to another. That, he thought, was all that might reasonably be expected from a laboratory spray test.

In effect, the relative corrodibilities of different materials, expressed on a percentage basis, would vary not only with the atmosphere to which they were exposed but with the physical conditions of exposure, such as the size and shape of the specimens and whether they were exposed vertically, horizontally or obliquely. To take an extreme case, the effect of moving specimens of ordinary and of copper-bearing steel from a highly polluted outdoor atmo- sphere to an equally polluted railway tunnel, where there was no rainfall, was to eliminate entirely the superior behaviour of the copper-bearing steel under the former conditions. Consequently it was reasonable to expect that if specimens of these two steels were exposed in the form of channels with the webs horizontal and the flanges pointing vertically downwards, the increased corrosion resistance of the copper-bearing steel would be manifested on the outer surfaces but not on the inner ones. It followed that the ratio of the loss in weight of the copper-bearing steel channel to that of the ordinary steel channel would be higher than if the experiment had been conducted on, say, flats of the two materials suspended vertically.

The question of the effect of the angle of exposure and of other geometrical factors on the relative corrodibilities of different materials had not yet been adequately studied. He felt that this might be found to explain some of the discrepancies to be noted in the literature. For instance, American claims for the superior resistance of certain low-alloy steels to atmospheric corrosion were more sweeping than had so far been justified by the experi- mental results of the Corrosion Committee; they referred to ratios of 5 or 6 to 1, in terms of the resistance of ordinary steel, whereas the Committee's results showed a ratio of about 2 to 1. The explanation might be, first, a difference between the American and British climates, secondly a time effect (many of the American tests had been in progress for longer periods than the British), and thirdly the fact that much of the American work had been conducted on thin sheets exposed obliquely, whereas the Com- mittee's specimens were heavy flats suspended vertically.

The differences in the resistance of low-alloy steels to atmo- spheric corrosion were associated in some way with the character of the rust formed on them during exposure; this had been noted in some of the earlier American work. In general, materials form- ing coarse rust were more corrodible than those forming fine rust. One reason was that the coarse rust retained moisture in contact with the metal surface; in fact, specimens carrying coarse rust were observed to dry less rapidly after rain than specimens carry- ing fine rust. The effect of the rust was influenced in turn by the orientation of the specimens. Thick lamellar rust would flake off at intervals from a vertical surface but would normally remain permanently on an upper horizontal one. The result was that the corrodibility of a material was determined by the type of specimen

tested, and, further, that, since materials forming different types of rust might not be affected in the same way, the relative corrodibilities of different materials would vary according to the conditions of exposure. Incidentally he felt that a fundamental investigation into the reasons for the differences in the types of rust formed on different materials might yield valuable practical results, since many cases of excessive corrosion were associated with the formation of gross adherent rust.

He hoped that these remarks would make it clear that there could be no such thing as an absolute table of corrodibility of different materials, even when exposed to similar types of atmosphere, and thus substantiate his statement that the results of the authors' laboratory tests were sufficiently good for all practical purposes. It was true, as would be seen from Fig. A, that their spray test gave relatively high figures for the less corrodible materials, but there was reason to hope that parallel series of experiments now in progress at the Chemical Research Laboratory, Teddington, by Dr. G. D. Bengough, F.R.S., and Dr. W. H. J. Vernon would lead to further improvement in this direction and usefully extend the results described in the present paper.

Mr. H. T. SHIRLEY (Sheffield) said that, as one of those who had taken an active part in the early stages of the development of the laboratory test for atmospheric corrosion, he found the paper of particular interest, and he was very interested to notice, now that results had been obtained which followed very closely the practical results of real atmospheric exposure, that one of the things which the Sub-Committee had always felt to be the right conditions for the test had proved to be so, i.e., that the solution should not be used for an immersion test but for a spray test, in which æration played a primary part and hydrogen evolution was kept at a minimum. That had been proved up to the hilt now that the test had come out very nearly satisfactory at the end of a long series of tests. The reason why the earlier tests had failed was that at that time it was not realised how important was the effect, protective and otherwise, of the corrosion product; therefore, in the early tests the specimens were simply sprayed and there was no washing treatment. He was sure that one of the main reasons for the success of the present test was the washing treatment, simulating the rainfall effect on the corrosion product, and another reason for the success was the choice of a solution such that the corrosion product was allowed to form, one might say, the right texture and to absorb the right substances to continue the corrosion of the damp material as it went forward to the drying part of the cycle. Those two points had made a great improvement in the test, and it was now in a very satisfactory state.

There was still something to be desired in the spread of the results, particularly with the more resistant materials, as compared

with the industrial atmosphere effects on the steels.   He thought that the Committee's tests had shown that Sheffield had the most corrosive atmosphere in the British Empire; there the differences were very marked, and the laboratory test had not quite brought out those great differences, but he had no doubt that, as had been hinted already, it fitted perfectly the particular atmosphere somewhere, and that was a point of great importance, because there was no doubt at all that before very long the spread would be corrected for the Sheffield atmosphere as a result of the tests that were now being carried out, and the effects of other atmospheres could be closely imitated.   Wherever the test was taken up or in whatever atmosphere it was considered, it would be necessary to have, as Dr. Swinden had suggested in presenting the paper, a range of bottles labelled with the atmospheres, and calibration would always be required for a particular locality.   That, together with the more difficult nature of the apparatus as compared with a simple " beaker " test which most people visualised as being the ideal, brought in one of the difficulties for the tester of small numbers of samples.   He thought the Sub-Committee had started with the simplest test that they could imagine which in some degree would produce atmospheric corrosion, because they hoped that it would be possible to place it in the hands of any investigator and say to him " There is the test which we feel is the most satisfactory; go ahead and use it yourself."   Unfortunately that had proved to be impossible and the developments had added complications. From the standpoint of a committee or a large-scale investigator that did not matter very much—it was not seriously complicated and it was foolproof—but from the point of view of the small investigator it did matter, and he would have either to wait for the Committee or to adopt the very simple test provided by Nature on the roof of a building.   If he carried out that test for a year he would find that his order of merit would compare very well with the order of merit found after a longer period of test.   The Sub-Committee had shown that a short-time test on the roof was not as satisfactory as the new test, which he thought had won a first-rate place, because it had brought a test within the bounds of a month which normally would have taken a year.   The authors of the paper and the Sub-Committee as a whole were to be congratulated on the way in which the test had now developed.   He hoped that in the very near future it would be possible to suggest to anyone who had the facilities for carrying out the test the appropriate solution and the appropriate apparatus for getting a 100% correct result in the space of a few weeks.

CORRESPONDENCE.

Dr. W. H. J. VERNON (Chemical Research Laboratory, Teddington) wrote that he gladly availed himself of the authors' invitation

to contribute to this discussion, particularly because of the opportunity it afforded of expressing his appreciation of the value and importance of their work. At Teddington they had had extended facilities for appraising this work, thanks to the very practical co-operation of the authors in supplying a duplicate of their spray apparatus for use in the Corrosion Section at the Chemical Research Laboratory. The object was twofold : (1) To repeat the Stocksbridge work, using precisely the same arrangement of apparatus, the same spraying liquid and the same series of specimens, with the view to checking the reproducibility of the method in another laboratory; and (2) to explore the possibility of effecting modifications, particularly from the point of view of incorporating the findings of the Teddington laboratory investigations on atmospheric corrosion.

So far as the first of these objects was concerned, three runs had been carried out, the numerical results of which were given in Table A, the corresponding orders of merit being shown in Table B, together with the orders of merit given by the Stocksbridge spray tests and the original field tests. It would be seen that, whilst the general order was confirmed, the number of departures from the original field test order was rather greater than in the authors' tests. Noteworthy irregularities were provided by steels O and L. In spite of these, however, and in spite of the empirical nature of the spraying liquid, it could be said that for the series of irons and steels used by the authors the sulphuric-acid/sodium-chloride

TABLE A.—*Results obtained in Spray Tests at Teddington, using " Stocksbridge Spray " (N/100 Sulphuric Acid, N/100 Sodium Chloride).*

Spraying carried out for 20 days, 60 cycles per day.

Materials Used (in Order of Merit given by Field Tests).	Mean Loss of Weight per Standard Specimen.* G.		
	1st Series.	2nd Series.	3rd Series.
Steel N .	0·60	0·65	1·05
,, L .	0·69	0·69	1·12
,, ZK .	0·66	0·68	1·09
,, O .	0·76	0·65	1·05
,, Z .	0·65	0·66	1·10
,, K .	0·68	0·72	1·09
,, XK .	0·79	0·70	1·21
Rail steel .	0·70	0·70	1·20
Staffordshire wrought iron .	0·78	0·70	1·22
Steel $X2$.	0·74	0·72	1·25
Ingot iron .	0·90	0·74	1·38
Aston-Byers iron .	0·87	0·73	1·34
Swedish Lancashire iron .	1·02	0·82	1·50

* Total area of standard specimen, 16 sq. in.

TABLE B.—*Orders of Merit in Field Tests and in Spray Tests at Stocksbridge and Teddington using "Stocksbridge Spray" (N/100 H₂SO₄,N/100 NaCl).*

	Field Tests (Table IV.).	Stocksbridge (I.) & (II.) Mean (Table III.).	Stocksbridge (III.) (Table V.).	Teddington.		
				1st Series.	2nd Series.	3rd Series.
1	Steel N	Steel N	Steel N	Steel N	Steel N	Steel O
2	,, L	,, L	,, L	,, Z	,, O	,, N
3	,, ZK	,, ZK	,, ZK	,, ZK	,, Z	,, ZK
4	,, O	,, O	,, O	,, K	,, ZK	,, K
5	,, Z	,, Z	,, Z	,, L	,, L	,, Z
6	,, K	,, K	,, K	Rail steel	Rail steel	,, L
7	,, XK	Rail steel	Rail steel	Steel $X2$	Steel XK	Rail steel
8	Rail steel	Staffs. W.I.	Steel $X2$	,, O	Staffs. W.I.	Steel XK
9	Staffs. W.I.	Steel XK	,, XK	Staffs. W.I.	Steel $X2$	Staffs. W.I.
10	Steel $X2$	,, $X2$	Staffs. W.I.	Steel XK	,, K	Steel $X2$
11	Ingot iron	Ingot iron	Ingot iron	Aston-Byers	Aston-Byers	Aston-Byers
12	Aston-Byers	Aston-Byers	Aston-Byers	Ingot iron	Ingot iron	Ingot iron
13	Swed. Lanc.	Swed. Lanc.	Swed. Lanc.	Swed. Lanc.	Swed. Lanc.	Swed. Lanc.

method afforded a reasonably close reproduction of the relative behaviour of the materials in an industrial atmosphere.

In the further tests a new criterion had been adopted, namely, the behaviour of a series of copper steels, of ascending copper content up to 0·5%, the characteristics of which had been well established in many field tests both in Britain and in America; it was generally accepted that up to 0·25% copper there was marked reduction in corrosion, but little further reduction between 0·25% and 0·5% copper. For the present purpose such a series of steels seemed to afford a better criterion than an arbitrary series for which the results of much more limited field tests were available. Accordingly, steels containing respectively 0·025%, 0·10%, 0·25%, 0·3% and 0·5% of copper were employed. It was desired, moreover, that the new tests should incorporate two primary environmental factors that had been established in the course of previous Teddington work, *viz.*, (1) that the major atmospheric constituent responsible for aerial corrosion in Britain was sulphur dioxide, and (2) that the atmospheric rusting of iron in industrial districts was actively promoted by disperse particles, probably mainly of ammonium sulphate.

It was hoped that a full account of this work would be available in due course. Meanwhile, it might be stated that tests involving the presence of sulphur dioxide in the spray and of sulphate particles on the metal had given remarkably faithful reproductions of the influence of copper; plots of corrosion against copper content fell steeply to 0·25% copper, and thence but slightly to 0·5% copper. The "Stocksbridge spray" (N/100 H₂SO₄,N/100 NaCl) entirely failed to reproduce these curves, the points being apparently sporadically distributed. On the other hand, some of the spraying systems, whilst bringing out perfectly the influence of copper, had compared unfavourably with the Stocksbridge spray when applied to the series

of steels used by the authors. Further work was in progress with the object of overcoming this difficulty, and promising results had in fact been obtained. It might, however, be fairly concluded that caution was necessary in assuming that the close reproduction of the " service " order of merit as shown in the Tables would necessarily be maintained for other groups of ferrous materials.

On matters of detail concerning the present paper, only one or two further points arose beyond those already discussed with the authors. At Teddington they had found it desirable, in the " drying " of the specimens (p. 169 P), to control the temperature of the heating chamber by means of a relay system. For the removal of rust (p. 170 P) before the estimation of loss of weight, they had found cathodic treatment in a 10% solution of sodium cyanide greatly advantageous; it was possible that some of the discrepancies in Table B would be eliminated by the consistent use of this method. They had also found it advantageous to use a different type of nozzle from that used by the authors. In the Teddington design, the air jet surrounded the liquid jet annularly and so ensured the coincident delivery of air and liquid. The third series of Teddington results (Table A) were obtained with a new nozzle, the first and second series with the old. The higher values obtained in the third series might be partly accounted for by the different nozzle, but other factors, particularly the atmospheric humidity and temperature at the time of the test, must also contribute in determining, for any given spray liquid, the magnitude, as distinct from the order of merit, of the results. The criterion of " acid attack " referred to by the authors in Conclusion (1) was presumably the evolution of hydrogen, but this point might perhaps be made quite clear. It might also be emphasised that no definite information was available as to the relative amounts of corrosion due to oxygen absorption or hydrogen evolution under the conditions of the tests. He felt that the authors were very much to be congratulated on this paper, which constituted a most valuable contribution to the technique of corrosion testing.

AUTHORS' REPLY.

The AUTHORS replied that they were very appreciative of the kindly manner in which the paper had been received. One of the authors (Dr. Swinden) had been of the opinion for a very long time that the question of testing the relative corrodibility of materials for outdoor exposure should, if possible, be brought into line with the determination of the physical properties of those materials, i.e., this additional property should be capable of laboratory interpretation and a comparatively rapid result be obtained, instead of the existing recommended procedure of exposing specimens in a particular outdoor atmosphere for a period of at least one year.

Due to perseverance with the Schroeder equipment and considerable research into the details of the spray cycle, coupled with great encouragement from the Laboratory (Corrosion) Research Sub-Committee, results had now been obtained on a representative series of materials, which compared favourably with the existing results of field tests. The authors did not suggest that the precise procedure laid down in the paper should be regarded as a *fait accompli*, but rather that the procedure used at Stocksbridge should be elaborated, with the object of still further improving the value of the results obtained. In fact, this was the objective when the original Stocksbridge equipment was transferred to, and readily accepted by, the Chemical Research Laboratory at Teddington. Some of the results obtained in the energetic pursuit of the method at Teddington were indicated in Dr. Vernon's contribution, which was referred to later.

Mr. Tucker emphasised the danger of interpreting the spray-test results as indicating other than the orders of merit for the industrial atmosphere against which they had been compared. The authors agreed with this view, with the proviso that they visualised modifications in the spray solution, together with the introduction of possible new treatments during the spray cycle, which would successfully enlarge the present limit of applicability of the test results. In regard to the question of pitting, this had not been taken into consideration in the presentation of the results, the authors having adopted the standard procedure employed by the Corrosion Committee. It was the agreed opinion of the Corrosion Committee that in true " atmospheric exposure " the importance of pitting was small compared with general rusting. The authors were aware, however, that in many cases of corrosive breakdown, pitting and perforation were the predominant criteria; attack on structural work in the vicinity of coke-ovens and gas-holders was a typical example of this.

Dr. Hudson's careful analysis of the results and encouraging comments were particularly welcome, coming, as they did, from one whose interest and experience in the subject were so well known. The authors were gratified to note the incorporation of the Stocksbridge spray test in a British Standard Specification for protective coatings. They noted, with interest, Dr. Hudson's curves of the Sheffield, Stocksbridge, Calshot and spray-test results; prior to the publication of the paper, they had compared the spray-test results with those of Dr. Hatfield and Mr. Shirley at Sheffield, and noted the agreement; the additional agreement with the Calshot results of Dr. Hudson and Dr. Banfield indicated that the necessary modifications in the method to produce satisfactory orders of merit for marine atmospheres might need to be of only a small order. The authors agreed with Dr. Hudson on the necessity for a fundamental investigation into the reasons for the differences in the types of rust formed on different materials. One step in this direction

had been the observation in regard to the formation, in the early stages of corrosion, of a copper-rich layer on low-copper steels, this copper-rich layer being regarded as a barrier against normal progressive rusting.

Mr. Shirley's excellent work in Dr. Hatfield's laboratories had been well known to the authors, both privately and as a result of his whole-hearted co-operation in the plans of the Laboratory Research Sub-Committee. Mr. Shirley had emphasised the point made by the authors in the paper, namely, that the essential feature of any laboratory test of this type was that the spray-test attack should be of the oxygen-absorption type, to the exclusion of hydrogen evolution. The authors actually spent three months on determining the size of spray nozzle, the optimum spray distance and the optimum blower pressure in order to satisfy themselves that they were achieving this end, as far as was practically possible. The choice of the mixed spray solution which produced the correct order of merit was, to the authors, the natural step, after it had been found from the work of previous investigators and from their own work that, alone, neither (a) various strengths of acid nor (b) mixed salt solutions gave the desired correlation with field-test results. They agreed with Mr. Shirley that the daily douching to detach loose rust was an important factor in the method, as the removal of this rust permitted the spray solution to " wet " the adherent rust, through which the rate of corrosion was maintained. Mr. Shirley had indicated that the Stocksbridge spray test was somewhat complicated and hence beyond the bounds of the small investigator. The main idea in the minds of the authors was that of devising a certain and rapid procedure which would differentiate between the various types of available structural materials in respect to their relative merits in outdoor exposure. Simple " beaker " types of test had failed to place these materials satisfactorily, as had been shown by a number of investigators; hence, the elaboration of the method which had been described in the paper followed. Furthermore, it was desired to assess, comparatively rapidly, the order of merit of the new corrosion-resisting materials of the low-alloy type which appeared from time to time from different parts of the world. Additional work at Stocksbridge since the publication of the paper had given satisfactory results in this direction, and the results of the field tests on these materials were awaited with interest, to compare them with the Stocksbridge spray results already reported to the Laboratory Research Sub-Committee.

The authors greatly regretted that present conditions did not permit of Dr. Vernon's attendance at the Meeting. They welcomed wholeheartedly, however, his written contribution and the complimentary evidence that it presented of the keen pursuit and elaboration of the method which was progressing at the Chemical Research Laboratory. As stated previously, the authors' original spray apparatus was readily accepted by Dr. Vernon (and Dr. Bengough)

for purposes of confirmation of the Stocksbridge results and additional research, as outlined by Dr. Vernon. The authors had no doubt that the Teddington procedures of (a) the use of sulphur dioxide in some form and (b) " inoculation " of the specimens by ammonium sulphate particles would lead to such improvement in the method as they had envisaged when the paper was published. Dr. Vernon's results in this direction on a series of copper steels were of particular interest, and the authors looked forward to the publication of Dr. Vernon's researches at some future date. The three further points were noted—temperature control of the drying chamber, the annular air-liquid jet and the use of cathodic 10% sodium cyanide for derusting—and would be considered in future work at Stocksbridge. Actually, the authors had found the strip heater in the new equipment to give a much more uniform temperature than the original carbon-filament lamps, and were satisfied that Clarke's solution did not attack any of the materials reported on in the paper. They were aware, however, that Clarke's solution attacked more highly alloyed steels—particularly chromium steels —and might need to revert to cathodic cyanide for later work. The annular air-liquid jet was definitely novel and should assist materially in the aeration condition postulated as a necessary feature of the test. They would agree with Dr. Vernon that the new type of jet had been mainly responsible for the increased attack obtained in the third series of the tests at Teddington, which was in line with the results obtained in the later work on the new equipment at Stocksbridge.

In regard to the question of " acid attack," in which, as suggested by Dr. Vernon, the evolution of hydrogen was used as the criterion, no attempt was made to measure quantitatively the degree of attack taking place. Experiments which showed acid attack were abandoned, consequent upon the authors' experiences with $N/20$ sulphuric acid, it being considered that acid attack would not be likely to have any satisfactory relation to true atmospheric corrosion.

THE CORROSION OF MILD AND COPPER-BEARING STEEL PANELS IN IRON-ORE WAGONS.*

By L. REEVE, Ph.D., B.Sc. (Scunthorpe, Lincs.).

(Figs. 2 to 4 = Plate X.)

SUMMARY.

The losses in weight of a series of mild-steel and copper-bearing (copper, 0·38%) mild-steel test panels fitted in the end plates of three 21-ton steel iron-ore wagons have been compared over a period of nearly three years. The panels weighed approximately 40 lb. each, and were bolted into steel frames welded on to the end plates, so that each wagon carried a plate of each kind of steel.

The panels were weighed at approximately six-monthly intervals after scrubbing with a dry wire-brush. The weight losses are tabulated and are shown graphically.

The results indicate that at the end of approximately three years the average loss in weight of the copper-steel panels amounts to only 38% of that of the mild steel, and that it is getting relatively even smaller.

The loss in weight is due to a combination of corrosion and mild abrasion by the masses of iron ore. It is probable that the good result given by the copper-bearing steel is partly due to the fact that the scale on the latter is tightly adherent to the underlying plate, and exerts a certain amount of protective action upon it.

There would appear to be little doubt of the economic value of using copper-bearing mild steels in the construction of wagons of the type described.

THE Corrosion Committee of the Iron and Steel Institute and the British Iron and Steel Federation have shown the beneficial effect of a small addition of copper to mild steel in resisting corrosion under various circumstances.

The present report presents the results of three years' corrosion tests on panels of mild and copper-bearing steel inserted in the end-plates of hopper-type ore wagons.

The wagons are of 21 tons capacity and have been on main-line service, transporting ore between the Appleby-Frodingham Steel Company's mines and its blast-furnaces, from April, 1937, till September, 1939. Since then they have been on internal service, transporting ore within the Company's Scunthorpe Works. The total mileage covered in their life is approximately 20,000 miles per wagon.

* Received July 11, 1940.

The general construction of the wagon may be seen from the photograph in Fig. 2. Apart from fittings, they are of all-welded construction, and for the purpose of these tests a suitable frame was welded into each end plate to carry the test panels, as shown in the diagram Fig. 1. The panels were bolted into position with countersunk bolts and were arranged to be flush with the inner surface of the end plate.

One of these test panels can just be made out in the nearest end panel of the wagon illustrated in Fig. 2, between the two angle
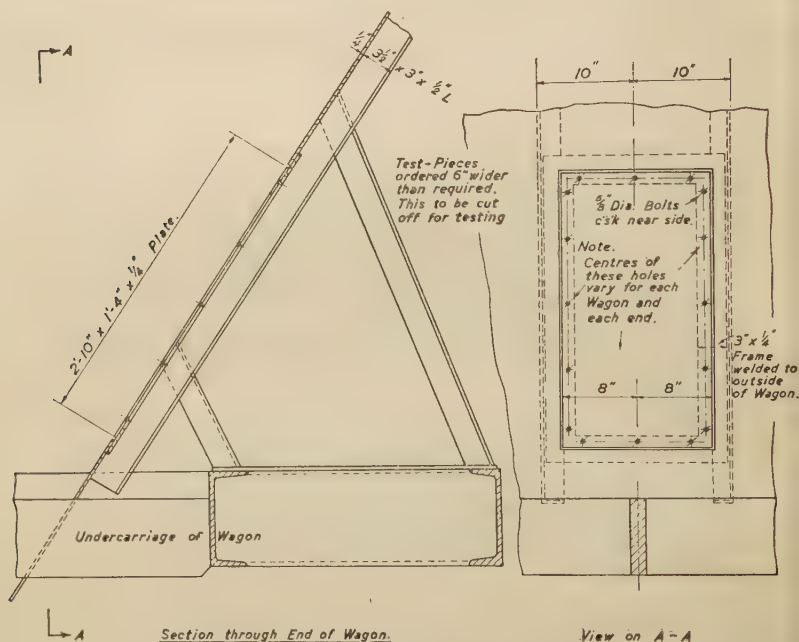
FIG. 1.—21-ton Iron-Ore Hopper Wagon.

stiffeners, but the panel can be seen much more clearly in the close-up photograph Fig. 3, which shows it bolted into position during service. The arrangement of the frame, both internally and externally, is illustrated in Fig. 4, a close-up view of a wagon with the panels removed.

The panels were unpainted except for identification marks on the outside, and an additional means of identification was therefore provided by saw cuts in the top edges of the panels. Correct replacement of the test plates was also ensured by adopting a slightly irregular arrangement of the bolt holes, the positions of which varied slightly for each wagon and each end.

PLATE X.

FIG. 2.—General View of Iron-Ore Wagon.
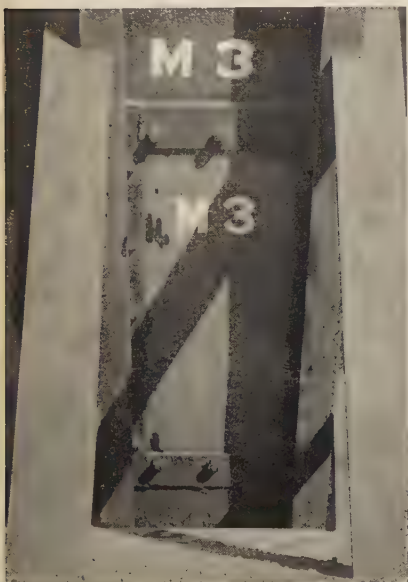
FIG. 3.—Panel in Position.
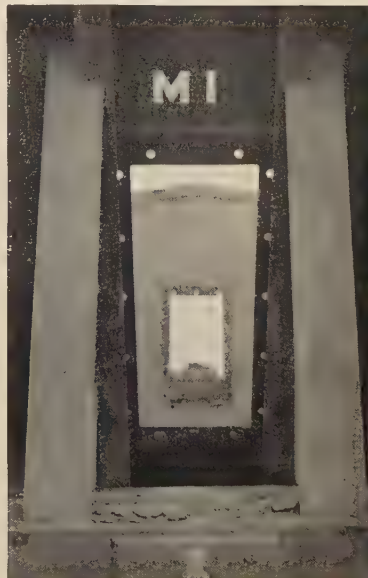
FIG. 4.—Panel Removed.

Three wagons were constructed in this manner, with a mild-steel panel at one end and a copper-bearing panel at the other end of each. The wagons were actually of copper steel throughout, except for the end plate carrying the mild-steel test panel, which was itself made of a similar mild steel ; the frame carrying this panel was also of mild steel.

The analyses of the test panels are recorded in Table I.

TABLE I.—*Analyses of Test Panels.*

Wagon No.	Panel No.	C. %.	Si. %.	S. %.	P. %.	Mn. %.	Cu. %.	Cr. %.	Ni. %.
F114	M1	0·16	0·014	0·045	0·028	0·63	...	...	...
	K2	0·14	0·024	0·052	0·041	0·55	0·38	...	...
F115	M3	0·16	0·019	0·044	0·026	0·64	0·023	0·047	0·045
	K4	0·14	0·028	0·053	0·042	0·54	0·39	0·054	0·049
F113	M5	0·15	0·017	0·045	0·027	0·62	...	...	...
	K6	0·15	0·024	0·053	0·041	0·55	0·38	...	...

The mild steel M, being made from virgin ore without outside scrap additions, is low in copper and other residual alloys.   The copper-bearing steel K is similar but has a copper addition of 0·38%.

The panels were 2 ft. 10 in. long by 1 ft. 4 in. wide by $\frac{1}{4}$ in. thick and weighed approximately 40 lb. each.   They were weighed to the nearest ounce on Avery platform scales (counterpoise-arm type) of one hundredweight capacity, the first weighings being as shown in Table II.

TABLE II.—*Three Years' Corrosion Test Results.*

Wagon No.	Panel No.	Original Weight (22/4/37).		Total Change in Weight, Oz., After Exposure for Approximately—						
				6 Months.	12 Months.	16 Months.	19 Months.	25 Months.	30 Months.	35 Months.
F114	M1	Lb. 40	Oz. 8	G 5	G 2	...	L 12	L 56	L 67	L 84
	K2	39	0	L 5	L 5	...	L 17	L 24	L 26	L 24
F115	M3	39	7	G 2	...	L 31	L 37	L 45	L 63	L 83
	K4	38	4	L 2	...	L 22	L 22	L 31	L 34	L 32
F113	M5	40	6	G 3	L 18	...	L 48	L 50	L 70	L 86
	K6	39	15	L 4	L 5	...	L 25	L 33	L 35	L 39

G = Gain in weight. L = Loss in weight.

Subsequent weighings were made at approximately six-monthly intervals after the panels had been scrubbed with a dry wire-brush,

which easily removed all loose " granular " rust and adherent ore, but did not remove any tightly adherent scale. Whilst this is not an absolute method of determining true scaling, it is the only convenient method when working with large panels. Moreover, it corresponds fairly closely to service conditions, where loose scale is removed by the abrasive action of the masses of ore in the wagon.

A new brush was used on all the panels at each weighing, and the scrubbing was done by the same operator. It is felt, therefore, that the results are comparable, and their general trend is confirmed by
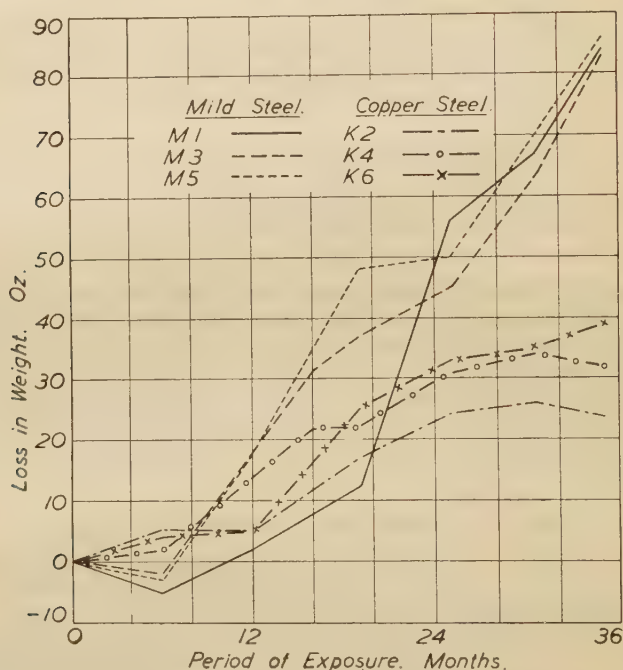
FIG. 5.—Corrosion Tests on Mild- and Copper-Steel Panels in Iron-Ore Wagons.

the reasonable agreement between the three sets of results after the first nineteen months of service.

The detailed results for nearly three years' service are given in Table II., and are plotted in Fig. 5.

It will be noted that whilst the mild-steel panels M are continuing to lose weight steadily, the copper-bearing panels K have slowed down to a very low rate of loss. This is partly accounted for by the fact that the scale on the latter is tightly adherent to the underlying plate and exerts a certain amount of protective action upon it.

The mild-steel scale, however, comes off fairly easily, and this no doubt occurs in service by impact and abrasion by the hard masses of ore. At the end of approximately three years, the average loss in weight of the copper-steel panels amounts to only 38% of that of the mild steel and is getting relatively even smaller.

The tests are being continued, but unless a sudden change occurs they will be stopped at the end of the fourth year, when the plates will be given a careful laboratory examination, including a final descaling in Clarke's solution to determine the residual scale.

Meantime, there would appear to be no doubt of the economic value of copper steels in wagons of the type described under conditions of combined corrosion and mild abrasion. It is hoped to extend the tests to other types of mineral wagons in the Company's service.

CORRESPONDENCE.

Dr. J. C. HUDSON (Birmingham) wrote that Dr. Reeve's paper was of particular interest to him because, in connection with the work of the Sub-Committee on Low-Alloy Steels of the Corrosion Committee,[1] he had been responsible for organising similar tests on a hundred coal hopper wagons, of which the floor plates had been constructed of four different types of structural steel, namely, an ordinary steel, a low-copper steel, a copper-manganese steel and a copper-chromium steel. The wagons were put into service in the latter half of 1939, and full details of the tests would be given when the Sub-Committee on Low-Alloy Steels published their First Report. These tests had been rendered possible through the kind collaboration of the London and North Eastern Railway and the steel company using the wagons.

The most interesting feature of the paper to him was the method by which the tests were being carried out. He had spent some time in endeavouring to devise a means whereby observations on built-in plates could be made quantitative, but had failed to solve the problem. Consequently he was fully able to admire the ingenious method adopted by Dr. Reeve of trepanning the large plates and inserting a smaller and removable piece of the same steel. The fact that Dr. Reeve was thus able to obtain quantitative data for the losses in weight of the steels greatly increased the value of his work. The method would also have the practical advantage of enabling a reduction to be made in the number of wagons required for tests of this type.

He would have preferred that the plates had not been cleaned by scratch-brushing before re-weighing them at each inspection, because the corrosion of the steel surface was materially affected (and generally increased) by contact with coarse rust. For example, in one experiment, Dr. T. A. Banfield and he had exposed two similar steel specimens in a horizontal position, but had placed some pieces of flaky rust on top of one. After 2·2 years' exposure the loss in weight of the specimen carrying the rust was 292 g. as compared with 222 g. for the other one. The explanation was that the presence of the rust maintained moisture in contact with the surface, and the specimen carrying rust was repeatedly observed to remain wet after rain for a longer time than the scale-free specimen. Consequently, the removal of the rust from the test surface by cleaning it at frequent intervals would interfere with the course of corrosion, and the curves shown by Dr. Reeve in Fig. 5 might not be true corrosion/time curves and fully representative of what would happen if the plates were left undisturbed. He was certain, however, that this fact did not invalidate the general conclusion reached by Dr. Reeve from his experiment that copper-bearing

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[1] Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation.

steel gave better results than ordinary steel under these conditions of service and that its use was well worth while.

He noticed that Dr. Reeve proposed to conclude the tests at the end of four years. He thought that it would be a mistake to do so and would suggest that they be continued for at least ten years; the interval between re-weighings could be increased, if thought desirable. Although it was not quite clear from the individual curves in Fig. 5, it would be found, if the mean results for all three wagons were plotted, that the loss in weight of the ordinary steel plates was a linear function of the time, *i.e.* :

Loss in weight in ounces $= 3 \cdot 0$ (number of months of service $- 8$),

whereas the rate of loss of the copper-steel plates suddenly became practically nil after 25 months. A further test period of twelve months would be insufficient to establish that corrosion of the copper-steel plates had virtually ceased, and it was therefore desirable to extend the experiments for a longer period.

AUTHOR'S REPLY.

Dr. REEVE, in reply, thanked Dr. Hudson for his very interesting remarks. With regard to the method of inserting the test panels, the most that was claimed was that the arrangement used was one which was comparatively simple and yet did not suffer from any very serious defects. An essential feature from the point of view of the tests described was that this system of fixing the panels did make it possible for them to be periodically removed and re-weighed. This was considered necessary in view of the difficulty of providing strict duplicates in tests of this character, and the consequent impossibility of removing successive plates for the various weighings, as was done in the main corrosion tests of the Iron and Steel Institute Corrosion Committee.

With reference to the effect of rust in contact with the surface of the steel under test, Dr. Reeve considered that, while Dr. Hudson's general statement was correct (*viz.*, that such contact between rust and steel might materially affect the corrosion rate), the example which he quoted was by no means parallel to the conditions of the test panels mentioned in the paper. In particular, there was no simulation of the repeated hammering and abrasion to which the wagons were subjected during the loading and discharging of the ore. One effect of this action in practice was that at times the rust formed, together with fine dust from the ore, became compacted into a shale-like scale, which was not removed by wire-brushing. As stated at the top of p. 194 P of the paper, only *loose* rust and ore were removed at each brushing, but the compact shale-like scale was allowed to remain until removed by being broken away during the normal usage of the wagon. This formation of

" shaly " scale appeared to be seasonal in character, and largely accounted for the " saw-tooth " form of the graph in Fig. 5.

The expressed intention of discontinuing the tests at the end of the fourth year was, as stated in the paper, based on the assumption that present rates of corrosion would continue. Any new developments, however, would certainly result in the continuance of the tests, and, in any case, consideration would be given to the possibility of leaving the test-pieces *in situ* for a period comparable with the total exposure period already covered, in an attempt to determine the influence of the periodical wire-brushings.

THE INFLUENCE OF SOME SPECIAL ELEMENTS UPON THE STRAIN-AGEING AND YIELD-POINT CHARACTERISTICS OF LOW-CARBON STEELS.*

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SUMMARY.

The influence of carbon, aluminium, copper, nickel, molybdenum, manganese, chromium, vanadium, niobium and titanium upon the strain-age-hardening properties of low-carbon steels was studied. It was found that these elements can be divided into two main groups, viz., those which show little or no tendency to combine with the carbon present in steel (aluminium, copper and nickel) and those which show definite tendencies to form carbides (molybdenum, manganese, chromium, vanadium, niobium and titanium). The former increase and the latter diminish the extent of strain-age-hardening of low-carbon steels.

It would seem that when sufficient of one of the elements of the second group is added to combine with all the carbon present the material does not strain-age-harden. The amount of alloying element required to bring this about varies with its chemical affinity for carbon, and the percentage is relatively small in the case of niobium and titanium. Thus it seems evident that one form of strain-age-hardening can be definitely traced to the presence of carbon and the condition in which it exists in the steel. It was also found that as the capacity for strain-age-hardening is diminished by increasing quantities of specially added elements, the intensity of the yield point diminishes, and no yield point is revealed on a stress-strain diagram when sufficient alloying element is present to prevent strain-age-hardening. Tentative explanations for the cause of the yield point are put forward.

THE work embodied in the present paper is a natural extension of the investigation dealing with the strain-age-hardening of mild steel published a short time ago by Edwards, Jones and Walters.[1] In that instance the specimens were subjected to tensile strains and then, after ageing at 250° C. for 1 hr., the tensile properties were again determined. On that occasion the degree of straining before ageing was in most cases confined to the amount of strain which normally takes place at the yield point. For this purpose the stress was slowly raised to the yield point, and then sufficient time was allowed for the strain to be completed while the stress was maintained at a constant value. In this way the amount of strain varied considerably according to the nature and condition of the material.

The measure of the age-hardening capacity was taken as being

indicated by the extent to which the yield points and ultimate-stress values were raised after straining and ageing. From the evidence obtained it was concluded that oxygen does not appear to play any direct part in the strain-age-hardening capacity of ordinary mild steel, at least so far as that quality is revealed by a rise in the yield point or ultimate breaking stress. It was shown that a steel containing an appreciable quantity of aluminium, and, therefore, presumably no " active " oxygen (*i.e.*, free to combine with iron), displayed the same tendency to strain-age-harden as all the other samples that were examined. In the work just referred to no attempt was made to study the influence of other elements upon strain-ageing.

In the present investigation it was decided to examine the influence of varying percentages of different elements upon the strain-ageing characteristics of low-carbon steels. For various reasons a constant degree of strain before ageing was used instead of the amount of strain which normally occurs at the yield point. In this way the results gave a more direct indication of the effects of the different elements upon the capacity for strain-age-hardening. The extent of this preliminary straining before ageing was $6 \cdot 0\%$ permanent elongation. This percentage was selected because it was large enough to be more than that likely to be produced at the yield stress for any of the specimens with which the authors would be dealing. In all cases the temperature of ageing was 250° C.

The results of the tensile tests shown in the accompanying Tables are the averages of at least two determinations for each set of conditions.

PREPARATION OF TEST SPECIMENS.

The various series of steels examined in the present investigation were made in an Ajax-Northrup high-frequency induction furnace, in a manner similar to that described previously by Edwards and Jones.[2] Sixteen pounds of Armco iron were melted in a sillimanite crucible, and, after the removal of the small quantity of slag formed, the requisite additions, in the form of either pure metals or carbon-free ferro-alloys, were made in order to bring the composition of the melt to the desired analysis. When the temperature of about 1600° C. was reached the molten steel was poured through a tundish lined with alundum into a cast-iron mould of $2\frac{1}{2}$ in. square cross-section and 12 in. long. The bottom 4 in. of the resulting ingot was hot-forged under a steam hammer at a neighbouring engineering works to a rod approximately $\frac{3}{8}$ in. in dia. This was pickled to remove the scale and then drawn down in easy stages, without any intermediate annealing, to a diameter of $\frac{11}{64}$ in. This thin rod was cut up into 12-in. lengths, which were annealed in an atmosphere of argon at temperatures ranging from 950° to 1050° C. and allowed to cool in the furnace. All the tensile tests were carried out on an Amsler 5-ton testing machine.

Samples containing varying quantities of the following elements were examined : Carbon, aluminium, copper, nickel, molybdenum, manganese, chromium, vanadium, niobium and titanium. A limited number of samples containing titanium along with one of the above-mentioned elements was also used. In addition to the main object of the work, tensile properties of all the materials used, in the fully annealed condition, were recorded. It was thought that information of this kind would be useful to those interested in the manufacture and use of mild steel. Throughout the present investigation the tensile properties were calculated on the basis of the original cross-sectional area of the specimen for both the annealed and the strain-aged conditions. In other words, no account was taken of the reduction in the diameter of the specimens due to the straining before ageing. In this way it was found easier to gauge the precise effects of strain-ageing.

ELEMENTS WHICH DO NOT COMBINE WITH CARBON.

Aluminium Steels.

For the examination of the influence of aluminium, five samples of the following compositions were made :

				No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Carbon.	%					Under 0·025		
Manganese.	%			0·26	0·23	0·28	0·25	0·26
Aluminium.	%			0·02	0·25	0·57	2·25	3·39
Copper.	%					0·09		
Nickel.	%					0·09		
Sulphur.	%					Under 0·023		
Phosphorus.	%					Under 0·010		

Steels Nos. 1 and 2 were annealed by heating to 950° C. in a nitrogen atmosphere for 1 hr. ; steels Nos. 3, 4 and 5 were annealed at 1050° C. in argon, followed by slow cooling. The results obtained

TABLE I.—Aluminium Steels.

(a) Fully Annealed.							(b) After Straining 6% and Ageing.			
Alu-minium. %.	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.	Cry-stals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.
0·02	11·92	2·88	15·91	19·79	31·8	35	19·13	2·33	21·86	15·3
0·25	11·82	2·64	15·85	20·04	24·3	36	19·19	2·25	21·88	13·5
0·57	11·98	2·44	16·36	20·46	26·9	32	19·35	2·00	22·40	14·6
2·25	12·08	1·23	18·05	23·00	25·0	15	21·05	2·04	25·36	12·9
3·40	16·10	0·85	22·74	26·94	19·7	13	25·58	2·25	29·92	12·2

from specimens in the fully annealed condition are recorded in Table I. (a) and plotted in Figs. 1 and 2; those obtained after straining and ageing are stated in Table I. (b). The essential changes brought about by ageing are plotted in Fig. 3. There is not much difference in the extent of age-hardening for any of the specimens, so far as this quality is revealed by the yield point after ageing minus the stress required to produce the strain before ageing. With regard to the effects of strain-ageing upon the ultimate breaking stress, the results are much the same—an increase of, say, 2·0 tons per sq. in. for specimens containing up to 0·57% of aluminium, rising to approximately 3·0 tons when 3·4% of aluminium is present.

Copper Steels.

Only three casts were specially made with varying copper contents, but the first sample of the manganese series can be regarded as filling the place of a low-copper sample for this series. The chemical compositions of the four samples were as follows :

					No. 1.	No. 2.	No. 3.	No. 4.
Carbon.	%	.	.	.		Under 0·025		
Manganese.	%	.	.	.	0·26	0·27	0·31	0·24
Copper.	%	.	.	.	0·09	0·27	0·60	2·97
Nickel.	%	.	.	.			0·09	
Sulphur.	%	.	.	.		Under 0·023		
Phosphorus.	%	.	.	.		Under 0·010		

The results of the tensile properties in the annealed condition are shown in Table II. (a) and plotted in Figs. 1 and 2, while the figures after straining and ageing are given in Table II. (b). The

TABLE II.—Copper Steels.

(a) Fully Annealed at 950° C. in Argon.							(b) After Straining 6% and Ageing.			
Copper. %.	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.	Cry-stals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.
0·27	12·52	2·31	17·50	21·10	24·3	35	20·62	1·96	24·88	12·9
0·60	14·48	2·70	19·02	22·59	23·8	47	22·25	2·13	26·29	12·8
2·97	21·50	3·77	24·25	26·91	17·7	77	28·39	3·32	30·75	11·0

difference between the initial yield points and the stress required to give 6·0% strain falls from 4·98 tons per sq. in. with 0·27% of copper to 2·75 tons when 2·97% of copper is present. The strain-ageing influence upon the yield point is 3·2 tons per sq. in. in each case, with the exception of the one with the highest copper content, for which it was 4·14 tons per sq. in. With regard to the effect of
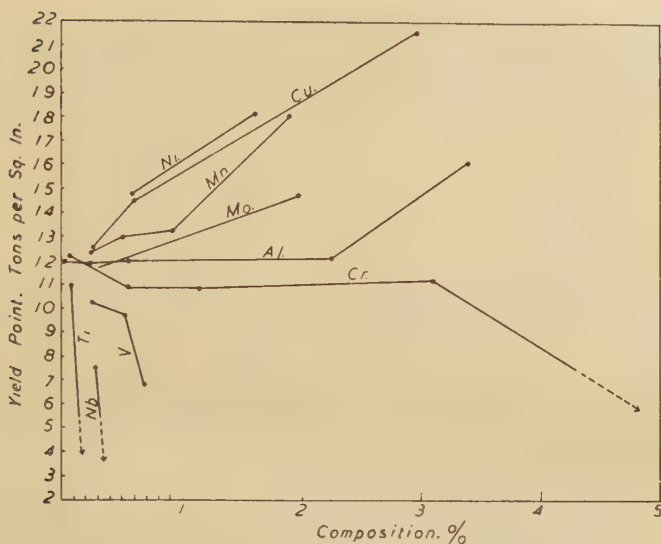
Fig. 1.—Yield Point in the Annealed Condition.

strain-ageing upon the ultimate-stress values, this is practically constant when the copper is between 0·27 and 2·97%, and corresponds to a hardening equal to about 3·75 tons per sq. in.
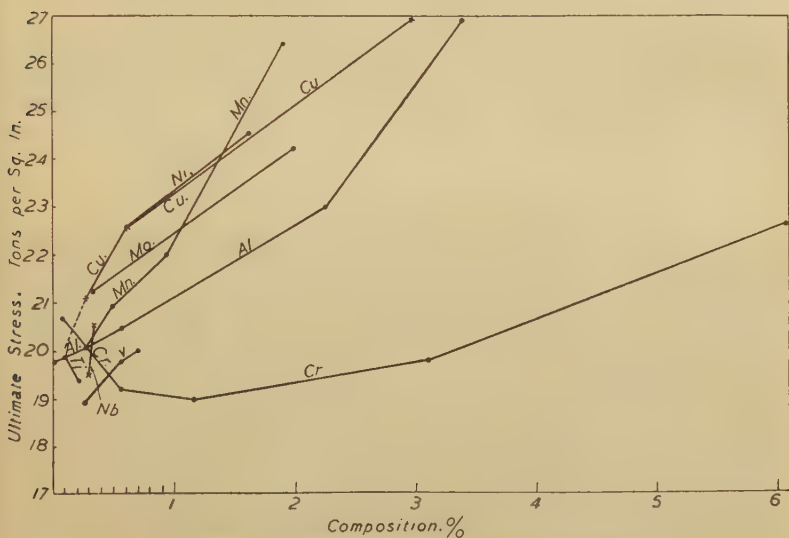
Fig. 2.—Ultimate Stress in the Annealed Condition.

Nickel Steels.

For the purpose of estimating the influence of nickel only two casts were specially made. These had the following compositions :

						No. 1.	No. 2.
Carbon.	%	.	.	.	.	Under 0·025
Manganese.	%	.	.	. .		0·29	0·31
Nickel.	%	.	.	.	.	0·60	1·61
Copper.	%	.	.	.	.	0·09

The results for the annealed and the strained and aged specimens are given in Table III., (*a*) and (*b*). For comparison with the other

TABLE III.—*Nickel Steels.*

(*a*) Fully Annealed at 950° C. in Argon.								(*b*) After Straining 6% and Ageing.			
Nickel. %.	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.	Cry-stals per mm.		Yield Point. Tons per sq. in.	Yield. Strain. %.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.
0·60	14·80	3·31	18·53	22·58	24·2	63		22·77	2·87	26·00	11·6
1·61	18·16	4·13	20·76	24·51	23·7	90		25·38	3·27	28·15	11·8

series, the results for the annealed specimens have been plotted in Figs. 1 and 2.

The curves in Fig. 3 show that nickel has a greater effect on the yield point after ageing than either aluminium or copper. Its effect on the ultimate stress is less than that of copper, but greater than that of aluminium.

ELEMENTS WHICH COMBINE WITH CARBON.

Aluminium, copper and nickel do not give rise to the formation of carbides when present in steel. Elements which are known to form carbides were next examined, namely, manganese, molybdenum, chromium, vanadium, niobium and titanium. There are wide differences in the intensities with which these elements combine with carbon when present in steels. In some instances they are known to share the carbon with the iron, giving rise to a mixture of two carbides, and even then the added element is only partly present as carbide and is partly dissolved in the ferrite solid solution. This is certainly what happens with manganese; in the case of chromium, however, there are reasons for believing that very little, if any, chromium is dissolved in the ferrite so long as its amount does not exceed that required to form $Cr_3C_2 + Fe_3C$, or $CrFeC$. It was

expected that one of the remaining elements would possess a still greater affinity for carbon and possibly be capable of preventing the formation of any carbide of iron, without the need for much of the special element in excess of that required for combination with the carbon.
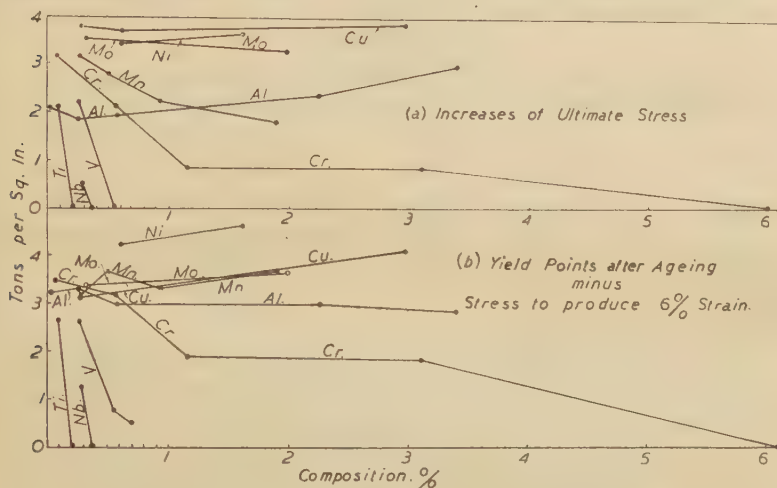
FIG. 3.—Effects of Ageing after Straining 6%.

Molybdenum Steels.

Two casts containing molybdenum were made, which had the following compositions :

					No. 1.	No. 2.
Carbon.	%	.	.	.	Under 0·025	
Manganese.	%	.	.	.	0·20	0·18
Molybdenum.	%	.	.	.	0·31	1·98
Nickel.	%	.	.	.	0·09	
Copper.	%	.	.	.	0·09	

TABLE IV.—Molybdenum Steels.

(a) Fully Annealed at 1000° C. in Argon.							(b) After Straining 6% and Ageing.			
Molyb- denum. %.	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ulti- mate Stress. Tons per sq. in.	General Elonga- tion. %.	Cry- stals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ulti- mate Stress. Tons per sq. in.	General Elonga- tion. %.
0·31	11·67	2·06	17·33	21·24	24·6	33	20·70	2·04	24·78	13·2
1·98	14·75	2·15	20·03	24·23	23·4	35	23·44	2·00	27·52	12·8

The results are recorded in Table IV. Apart from the fact that both specimens give relatively high figures for the stress required to produce a permanent strain of 6·0%, the results call for no special comment. They both show strain-age-hardening to quite a marked degree ; this is evident in both the yield points and the ultimate-stress values.

Manganese Steels.

In order to examine the influence of manganese four samples were made. They had the following chemical compositions :

				No. 1.	No. 2.	No. 3.	No. 4.
Carbon. % .	.	.	.		Under 0·025		
Manganese. % .	.	.	0·26	0·50	0·93	1·90
Copper. % .	.	.	.		0·09		
Nickel. % .	.	.	.		0·09		
Sulphur. % .	.	.	.		Under 0·023		
Phosphorus. % .	.	.	.		Under 0·010		

The tensile properties of these materials in the fully annealed condition are recorded in Table V. (a) and in Figs. 1 and 2. The

TABLE V.—*Manganese Steels.*

(a) Fully Annealed at 950° C. in Nitrogen.							(b) After Straining 6% and Ageing.			
Man-ganese. %.	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.	Cry-stals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.
0·26	12·31	3·20	16·01	20·05	24·4	27	19·28	2·13	23·22	12·6
0·50	12·93	2·96	16·40	20·94	27·4	27	20·09	2·42	23·73	14·2
0·93	13·24	2·66	17·36	21·99	25·6	32	20·68	2·16	24·21	14·1
1·90	18·08	2·61	22·22	26·40	21·6	60	25·90	3·12	28·20	8·5

data relating to the effects of straining and ageing are given in Table V. (b), and the important differences that have been brought about by straining and ageing are shown in Fig. 3. The yield points after ageing were just as clearly defined as they were in the original annealed condition. The difference between the new yield points and the stresses required to produce the 6·0% strain varies very little, and as these differences are not in direct accord with the manganese percentages, it would seem that this element, within the limits of 0·26 and 1·90%, is without influence upon strain-ageing so far as the yield points are concerned.

The position is not the same when the data for ultimate breaking stresses are examined, for, as will be observed from the figures in Table V. and the plotted results in Fig. 3, there is quite a noticeable

decrease in the extent of the age-hardening as the manganese content is raised. For example, the hardening is represented by 3·17 tons for the specimen containing 0·26% of manganese, a figure which becomes progressively less as the manganese increases up to 1·9%, when the ultimate stress in the strain-age-hardened condition is only 1·8 tons higher than that of the annealed material.

Chromium Steels.

To study the influence of chromium five casts of the following compositions were made :

				No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Carbon.	%	.	.			Under 0·025		
Manganese.	%	.	.	0·23	0·29	0·29	0·29	0·29
Chromium.	%	.	.	0·076	0·56	1·15	3·10	6·10
Nickel.	%	.	.			0·09		
Copper.	%	.	.			0·09		
Sulphur.	%	.	.			Under 0·023		
Phosphorus.	%	.	.			Under 0·010		

The results are presented in Table VI. and illustrated diagrammatically in Figs. 1, 2 and 3. There is a drop in the initial yield point of a little over one ton per square inch as the chromium content is raised from 0·1 to 0·56%, after which there is very little change until the chromium is increased from 3·10 to 6·10%. At this stage there is a marked drop, namely, from 11·23 to 7·37 tons per sq. in. There are only small variations in the stresses required to give a

TABLE VI.—*Chromium Steels.*

	(a) Fully Annealed at 950° C. in Argon.						(b) After Straining 6% and Ageing.			
Chromium. %.	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ultimate Stress. Tons per sq. in.	General Elongation. %.	Crystals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ultimate Stress. Tons per sq. in.	General Elongation. %.
0·076	12·18	2·56	16·52	20·67	25·6	35	20·00	2·21	23·82	13·0
0·56	10·87	2·42	14·99	19·19	25·7	30	18·16	2·00	21·32	13·4
1·15	10·86	2·54	15·12	18·96	25·8	37	17·01	1·58	19·78	19·0
3·10	11·23	2·32	15·97	19·80	24·2	37	17·81	1·50	20·65	15·7
6·10	7·32	0·36	18·25	22·65	23·4	37	...	...	22·52	17·5

permanent strain of 6·0% in the first four members of the series, but a large difference in the case of the one containing the highest chromium. Further, Table VI. and Fig. 3 indicate that, as regards both the yield point and the ultimate-stress values, there is a pronounced decrease in the amount of strain-age-hardening in each case when the chromium content is above 0·56%. This tendency is

greater when 6·1% of chromium is present; in other words, this last steel does not strain-age-harden. In this instance no clearly defined yield point was evident in the annealed or in the strained-and-aged conditions, the stress-strain diagram being very similar to that of a non-ferrous metal or alloy. It is thus evident that the age-hardening, which for the time being is presumed to be due to the presence of carbon, can be neutralised by chromium, and that this effect is associated with the disappearance of the yield point. It must be admitted, however, that far more chromium was required to eliminate the yield point and prevent the material from possessing strain-age-hardening qualities than is needed to form Cr_3C_2 with the 0·02% of carbon present. It seems probable that the whole of the carbon cannot combine with chromium unless there is a substantial excess of chromium present. Under these conditions the character of the ferrite must be changed by the solution of chromium in it.

Vanadium Steels.

The next element considered was vanadium; three casts were made having the following compositions :

		No. 1.	No. 2.	No. 3.
Carbon. % .	.		Under 0·025	
Manganese. %	.	0·30	0·32	0·26
Vanadium. %	.	0·26	0·55	0·69
Nickel. % .	.		0·09	
Copper. % .	.		0·09	
Sulphur. % .	.		Under 0·023	
Phosphorus. % .	.		Under 0·010	

The results are recorded in Table VII. Part (a) of the Table and Fig. 3 indicate that the strain-age-hardening, as measured by either

TABLE VII.—*Vanadium Steels.*

(a) Fully Annealed at 1000° C. in Argon.							(b) After Straining 6% and Ageing.			
Vana-dium. %.	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.	Cry-stals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.
0·26	10·21	2·29	14·99	18·92	28·1	23	17·63	1·83	21·14	15·5
0·55	9·69	1·67	15·81	19·78	27·1	29	16·58	1·46	19·80	17·8
0·69	6·80	0·48	15·71	20·01	23·9	33	16·24	0·96	20·03	18·0

the yield point or the ultimate-stress values, is low in the sample containing 0·26% of vanadium; it becomes even less with 0·55%

of vanadium, and is absent with 0·69%.   In the sample containing 0·69% of vanadium no real yield point could be detected on the stress-strain diagram.   This smaller quantity of vanadium required, as compared with chromium, to bring about these changes in the properties is probably due to the much stronger affinity of vanadium for carbon.

Niobium(-Tantalum) Steels.

In this instance only two samples were made, having the following compositions :

				No. 1.	No. 2.
Carbon. %	.	.	.	Under 0·025	
Manganese. %	.	.	.	0·21	0·25
Niobium. %	.	.	.	0·28	0·36
Tantalum. %	.	.	.	0·05	0·06

Unfortunately the ferro-alloy used for the purpose of introducing the niobium contained an appreciable amount of tantalum. There is, therefore, some uncertainty as to the extent to which the observed changes can be attributed to either one or the other of these elements.   However, attention having been drawn to this doubt, it is proposed to regard the effects as being due to niobium. The results given in Table VIII. indicate that 0·28% of niobium

TABLE VIII.—Niobium(-Tantalum) Steels.

Nio-bium, Tan-talum. %.	(a) Fully Annealed at 1000° C. in Argon.						(b) After Straining 6% and Ageing.			
	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.	Cry-stals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.
0·28 Nb 0·05 Ta	7·49	0·50	15·74	19·47	24·3	16	17·03	1·37	20·01	14·3
0·36 Nb 0·06 Ta	...	...	16·32	20·52	26·2	27	...	...	20·36	19·7

materially diminishes the intensity of the yield point and decreases the degree of strain-age-hardening, as regards the rise in both the yield point and the ultimate stress.   Further, in the sample containing 0·36% of niobium no yield point was observed either in the annealed condition or after straining and ageing.   The difference in the ultimate stress after straining and ageing is so small as to be within the range of experimental error.

Titanium Steels.

To examine the influence of titanium, two samples of the following compositions were made :

		No. 1.	No. 2.
Carbon. % .	. . .	Under 0·025
Manganese. %	. . .	0·23	0·30
Titanium. %	. . .	0·085	0·21
Nickel. % .	. . .	0·09
Copper. % .	. . .	0·09
Sulphur. % .	. . .	Under 0·023
Phosphorus. %	. . .	Under 0·010

The results are given in Table IX. There is quite a marked age-hardening effect in the sample containing 0·085% of titanium, but none in that containing 0·21% ; for the latter no yield point could be detected on the stress-strain diagram. Thus it is evident that only a small percentage of titanium—something between 0·085 and 0·21%—is necessary to prevent strain-age-hardening, on the one hand, and to cause the material to show no yield point, on the other. This is thought to be due to the titanium combining

TABLE IX.—*Titanium Steels.*

	(a) Fully Annealed at 1000° C. in Argon.						(b) After Straining 6% and Ageing.			
Titan-ium, %.	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.	Cry-stals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.
0·085	10·96	2·08	16·04	19·88	26·1	25	18·69	1·87	21·99	13·5
0·21	...	...	15·35	19·37	26·1	19	...	...	19·34	23·2
The latter non-ageing steel was cold-drawn and low-temperature annealed to produce small crystals.
0·21	6·92	0·42	...	20·96	28·4	...	...	...	...	...
0·21	7·21	0·42	16·54	...	...	...	16·35	0·42	20·96	21·2

with the whole of the carbon present and forming an inert carbide of titanium. In all probability this carbide is insoluble in ferrite, and it would seem that a comparatively small excess of titanium need be present to ensure that the whole of the carbon will combine with it. It is also possible that the presence of titanium prevents the carbon which may be dissolved in the ferrite from being pre-cipitated as a result of straining and ageing. In other words, carbon when associated with titanium and dissolved in ferrite is not precipitated.

Miscellaneous Alloys containing Titanium.

It was thought interesting to extend the research to a study of the influence of titanium in the presence of more carbon than had been dealt with so far, and also of the effect of titanium in the presence of other elements, such as copper and nickel, which appear to increase the strain-age-hardening capacity.

High-Carbon Titanium-Steel Series.—The two following carbon-titanium samples were made :

					No. 3.	No. 4.
Carbon. %	.	.	.	.	0·085	0·095
Manganese. %	.	.	.	.	0·13	0·17
Titanium. %	.	.	.	.	0·20	1·08

From the results listed in Table X. it will be seen that in the sample with 0·20% of titanium and 0·085% of carbon the strain-age-hardening quality and the yield-point characteristics have returned. This is what was expected from considerations already referred to. In other words, there is substantially more carbon present than is necessary to satisfy the carbide-forming capacity of 0·20% of titanium. The sample containing 1·08% also gave small indications

TABLE X.—*High-Carbon Titanium Steels.*

Carbon, Titanium. %.	(a) Fully Annealed at 1000° C. in Argon.						(b) After Straining 6% and Ageing.			
	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ultimate Stress. Tons per sq. in.	General Elongation. %.	Crystals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ultimate Stress. Tons per sq. in.	General Elongation. %.
0·085 C 0·20 Ti	}16·22	3·45	19·59	23·07	23·7	78	22·71	2·25	25·45	11·1
0·095 C 1·08 Ti	...	...	20·41	24·93	23·8	37	21·13	1·46	25·50	13·7

of age-hardening after straining, although the proportion of titanium present was considerably greater than the titanium/carbon ratio of 10 : 1 which was sufficient to prevent age-hardening when the carbon present was only 0·02%. Thus, as the carbon increases, a relatively larger proportion of titanium is required to suppress the strain-age-hardening qualities of steel.

Copper-Titanium-Steel Series.—In order to obtain evidence whether the addition of titanium in alloys containing copper would prevent this strain-age-hardening from taking place, two alloys, one containing 0·20 and the other 0·27% of titanium and both containing 0·6% of copper, were made. The results are recorded in Table XI. The sample containing 0·20% of titanium gave a clear indication of strain-age-hardening, as observed from the yield point, but this was very much less marked than in the corresponding copper

alloy containing no titanium. There were only small indications of hardening as revealed by the ultimate-stress tests. The sample containing 0·27% of titanium showed no real yield point and no change of properties as a result of ageing after straining. Here, again, the evidence points to the conclusion that strain-age-hardening, in all of the samples under consideration in this investigation, is due to the presence of small quantities of carbon, and that the effects of this carbon can be neutralised by the addition of a suitably small quantity of titanium and larger amounts of other elements. This is in accordance with the view that it is the carbon dissolved in the ferrite which is responsible for the hardening that occurs on ageing after straining. A comparison of the data for the annealed copper-titanium samples with those for the specimens containing the same percentage of copper but no titanium reveals that the ultimate-stress and general-elongation values are the same. Thus, the presence of titanium has not modified the tensile properties of

TABLE XI.—*Copper-Titanium Steels.*

(a) Fully Annealed at 1000° C. in Argon.							(b) After Straining 6% and Ageing.			
Copper, Titanium. per %.	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ulti-mate Stress. Tons per sq. in.	General Elonga-tion. %.	Cry-stals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ulti-mate Stress. Tons per sq. in.	General Elonga-ton. %.
0·59 Cu 0·20 Ti }	9·19	...	17·96	22·23	24·4	30	19·06	1·46	22·58	16·3
0·57 Cu 0·27 Ti }	9·41	0·61	17·73	22·17	25·4	26	18·70	1·50	22·53	15·8

the material at the breaking stage, in spite of the fact that it may be presumed to have removed the carbon from solution in the ferrite. The sample without titanium, however, is less plastic during the early stages of deformation. Facts of this kind might be found to have a bearing on the question as to whether titanium reduces the amount of carbon dissolved in ferrite or merely prevents the carbon from being precipitated from solution by straining and ageing.

Apart from the remarks which have been made concerning carbon, it can be concluded from these experiments that copper, of itself, does not cause strain-age-hardening. Its only effect apparently is to intensify the influence of carbon when that element is dissolved in ferrite. There are two possible explanations of the function of copper in this connection, namely, (a) it increases the solubility of carbon in slowly cooled ferrite and thus causes a larger amount of carbon to be precipitated during straining and ageing ; or (b) it brings about a more complete precipitation of the dissolved carbon during straining and ageing. Either of these possibilities would explain the

observed facts, but the available evidence is insufficient to justify the selection of one in preference to the other.

Nickel-Titanium Steel.—To determine whether the introduction of titanium into a low-carbon nickel steel would have the same effect as it did in the copper steels just described, an alloy containing 1·61% of nickel and 0·26% of titanium was prepared. The results,

TABLE XII.—*Nickel-Titanium Steel.*

Nickel, Titanium. %.	Yield Point. Tons per sq. in.	Yield Strain. %.	Stress for 6% Strain. Tons per sq. in.	Ultimate Stress. Tons per sq. in.	General Elongation. %.	Crystals per mm.	Yield Point. Tons per sq. in.	Yield Strain. %.	Ultimate Stress. Tons per sq. in.	General Elongation. %.
(a) Fully Annealed at 950° C. in Argon.							(b) After Straining 6% and Ageing.			
1·61 Ni 0·26 Ti	11·50	0·58	20·15	24·61	23·3	79	21·06	1·45	24·82	15·9
Nickel Steel for Comparison.										
1·61 Ni	18·16	4·13	20·76	24·51	23·7	90	25·38	3·27	28·15	11·8

shown in Table XII., indicate that the addition of titanium produced a steel which had only a small yield point and gave very little indication of strain-age-hardening. Indeed, by loading at a constant rate, no yield point was detected (*see* Fig. 6 (*c*)), and the ultimate stress age-hardening was within the range of experimental error.

CRYSTAL SIZE.

In view of the well-known influence of crystal size upon the mechanical properties of metals and their alloys, and the possibility of there being some connection between the degree of strain-age-hardening and the mechanical properties of mild steels, representative samples of each composition were examined and the size of the crystals present was estimated. For this purpose micrographs of fully annealed specimens were used. The results, expressed in terms of the number of crystals per linear millimetre, have been plotted in Fig. 4 against the corresponding compositions of the different series. On comparing these curves with those for the yield points and ultimate-stress values in Figs. 1 and 2, many features of similarity will be noticed, but the relationship is not complete.

From an examination of the crystal-size curves in Fig. 4 and a comparison of these with the curves in Fig 3, no rule applicable to all cases can be formulated. For example, in the cases of nickel and copper the degree of strain-age-hardening in members of each particular series is about the same, but there is a very substantial decrease in the size of the crystals as the precentage of each of the elements present is raised. In the manganese series, on the other

hand, the maximum strain-age-hardening diminishes as the manganese is increased, but the size of the crystals decreases. With aluminium there is an increase in the maximum strain-age-hardening, but the size of crystal present increases as the amount of aluminium becomes greater. In the chromium series there is a marked decrease in the capacity of the steel to age-harden as the chromium content increases, and this becomes zero with 6·0% present, but the size of the crystals throughout the series remains practically constant.
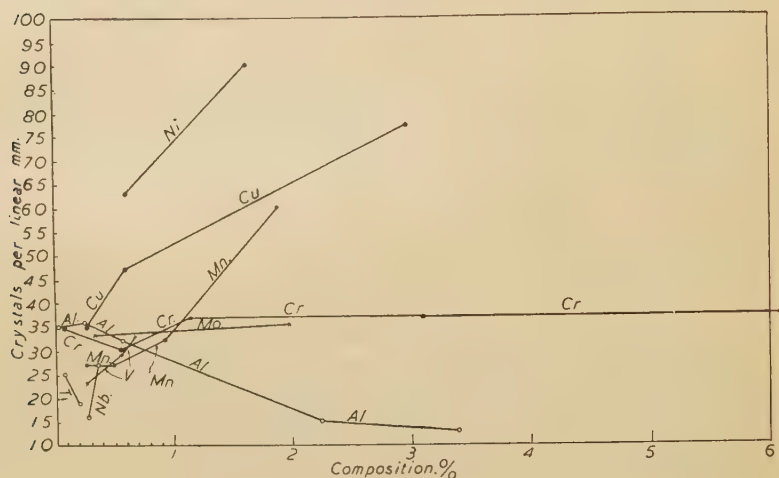
Fig. 4.—Crystal Size.

The effects of the carbide-forming elements in reducing the strain-age-hardening qualities of steel seem thus not to be due to the presence of large crystals. In further support of this it is only necessary to refer to the results for the sample containing 0·20% of titanium with 0·02% of carbon. A piece of this material was heavily cold-drawn and low-temperature annealed to give very small crystals. Even after this treatment there was no change in the maximum-stress values after straining and ageing.

BRIEF DESCRIPTION OF A SELECTED NUMBER OF STRESS-STRAIN DIAGRAMS.

It is now proposed to give a brief description of a limited number of typical stress-strain diagrams from amongst the large number which have been taken during the present work. Fig. 5 (a) contains two curves, one for the annealed specimen and the other after straining and ageing, for the first member of the manganese series, containing 0·26% of manganese and no other added element. In

both curves there is a clearly defined yield point, and in the annealed
state this corresponds with an elongation of 3·20%. In Fig. 5 (b)
the two curves from the steel containing 6·10% of chromium are
reproduced. In the fully annealed state there are only traces of a
break in the curve, but nothing in the nature of a real yield point.
There is no yield point after strain-ageing and no age-hardening as
revealed by the ultimate breaking stress. The curves for the steel
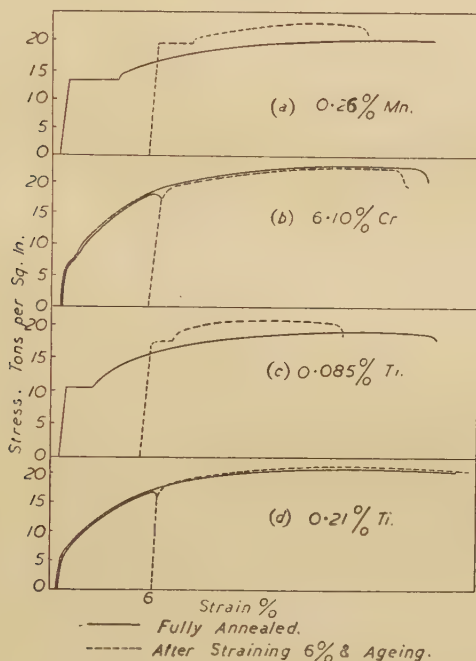
FIG. 5.—Typical Stress-Strain Diagrams (see also Fig. 6).

with 0·085% of titanium, shown in Fig. 5 (c), indicate well-defined
yield points and marked age-hardening after straining. The curves
for the specimens containing a still higher percentage of titanium,
namely, 0·21%, give no indication of a yield point, either in the
annealed state or after strain-ageing, and there is no difference in the
breaking stress of the two, see Fig. 5 (d). The character of the curves
is quite different when the carbon content is higher, even though the
titanium content is the same as that just mentioned. Thus, in Fig.
6 (a), with 0·085% of carbon and 0·20% of titanium, a pronounced
yield point is again present and strain-age-hardening takes place.
With 0·095% of carbon and 1·08% of titanium there are no indica-

tions of a yield point in the fully annealed state, *see* Fig. 6 (*b*), but there is a small yield point after strain-ageing and a little increase in the ultimate stress.

The last curves, shown in Fig. 6 (*c*), are for the two steels con-
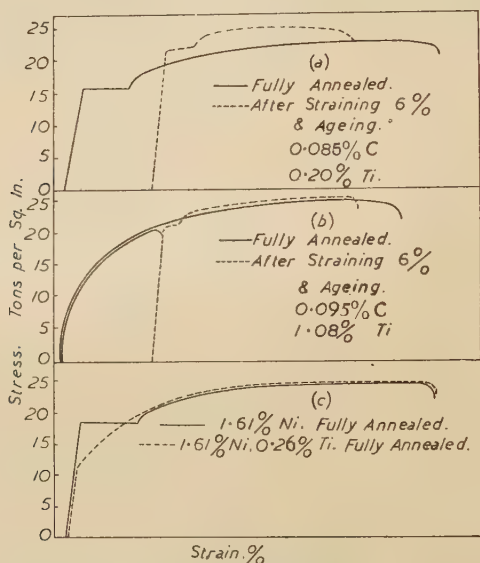
FIG. 6.—Typical Stress-Strain Diagrams (*see* also Fig. 5).

taining 1·61% of nickel, one of them with no titanium and the other with 0·26% of that element. There is a very marked yield point corresponding to 3·27% elongation with no titanium present, but no yield point in the specimens containing titanium.

GENERAL DISCUSSION OF RESULTS.

As previously indicated, the elements of which the influence upon the strain-age-hardening qualities of low-carbon steels has been studied can be very conveniently divided into two more or less distinct groups. The first of these includes aluminium, copper and nickel, which do not enter into chemical combination with carbon when they are present in steel. All samples in this group show unmistakable signs of age-hardening after straining, and there is a tendency for the degree of this hardening to become more evident as the percentage of the element present increases. The results obtained with samples which fall within this group do not call for any special comment.

The elements falling within the second group are those which are

known to combine with carbon. The extent to which this combination proceeds when the elements are individually present in steel varies considerably. The following elements belonging to the second group have been examined in the present investigation : Molybdenum, manganese, chromium, vanadium, niobium and titanium. This order is in accordance with the recognised affinity with which the elements combine with carbon when present in steel. Before proceeding to discuss the influence of these elements on strain-age-hardening, it may be useful to make the following observations.

For a long time it has been recognised that carbon may be at least partly responsible for the increased hardness which develops on ageing previously strained mild steel. Thus, Pfeil [3] has shown that mild steel from which all the carbon has been removed, provided that the oxygen has also been reduced to something approaching zero, does not possess any strain-age-hardening qualities. So far as the carbon is concerned, Pfeil concluded that the age-hardening for which this element is responsible is due to the fact that that carbon which is dissolved in the ferrite at the ordinary temperature, about 0·007%, is partly precipitated as a result of the straining and ageing. Thus, he considered the phenomenon to be a form of what is generally described as " precipitation-hardening." On the other hand, Andrew, [4] who also considers strain-age-hardening to be due to carbon, has put forward a more complex explanation of the possible function of carbon. Quite briefly, it may be stated that Andrew's conception is that straining causes some of the undissolved carbide of iron to go into solution, that this solid solution is decomposed on ageing after straining, and that precipitation-hardening thus takes place. The authors feel they can accept this explanation if it can be proved that small amounts of cold-work give rise to an increased quantity of carbide of iron being taken into solid solution by iron. For the moment the outstanding fact is that carbon is one of the elements which will cause mild steel to strain-age-harden.

At an early stage in this work it was expected that one of the elements used would have such a strong affinity for carbon that, when present in sufficient quantity in a low-carbon steel, it would prevent the formation of carbide of iron and give a special carbide which might also be insoluble in ferrite ; such a steel would not show any tendency to strain-age-harden because there would be no possibility of carbon precipitation.

Kuroda [5] has put forward the view that the well-known yield-point phenomenon, which is peculiarly characteristic of mild steel, is not an intrinsic property of iron itself but is due to the enrichment of carbon, or other elements, at the boundaries of the ferrite crystals. His view is that this film of, say, strong cementite supports the load during a tensile test to an extent which is well beyond the capacity of the ferrite grains themselves, and, therefore, once the stress gets beyond that at which these films are broken, the whole stress is

thrown upon the interior of the ferrite crystals, and a pronounced amount of plastic deformation takes place without further increase in the applied stress. Hence, any treatment which removes this film will cause the yield-point phenomenon to disappear. Kuroda describes a number of experiments which he carried out with a view to testing his ideas, and many of the results lend support to his views.

Previously it had been generally accepted that the reinforcing effects of the crystal boundaries, which give rise to the well-known yield-point characteristics, were due to the natural properties of the metal itself, and in no way due to the presence of a foreign element.

In the light of previous work it was recognised that difficulty might be experienced in obtaining reliable evidence to test Kuroda's ideas. For example, even if it is assumed that the yield point is caused by the presence of carbon, it is known that the quantity of carbon need only be quite small. Thus, in their recent work, Edwards, Jones and Walters [1] found that well-developed yield points were observed in material containing no more than $0 \cdot 02 \%$ of carbon. Further, they found that the intensity of the yield point could be changed by varying the crystal size. In other words, it could be diminished by increasing, and intensified by decreasing, the crystal size, by modifying the heat treatment of a given material. The yield point was shown to fade to almost zero in a steel with $0 \cdot 02 \%$ of carbon in specimens containing rather large crystals. These facts indicate how difficult it may be to decide to what extent the disappearance of the yield point is due to the absence of carbon or the form in which it is present on the one hand, or to the presence of large crystals on the other.

It was for these reasons that the authors hoped to select an element which would completely combine with the carbon present and form a carbide which would be almost, if not completely, insoluble in ferrite. Under these conditions no film of carbide of iron at the crystal boundaries, such as that postulated by Kuroda, could be formed. In any case, if these conditions could be satisfied and no yield point was revealed on a stress-strain diagram of such a specimen, then it would be a step in support of Kuroda's suggestion as to the fundamental cause of the well-known yield point in mild steel.

Turning, however, to the problem of strain-age-hardening, it will be found on reference to the tabulated results obtained for those elements which form carbides that they all show unmistakable indications of diminishing the degree of strain-age-hardening as the percentage of the element increases. This can be more clearly observed by examining the data dealing with the effects of the elements upon the ultimate breaking stresses ; an approximate idea of the comparative quantitative influence of the various elements can be gained from the following figures, which include experimental results taken from the tabulated data already referred to :

Element.				Amount present. %.	Rise in the Ultimate Breaking Stress after Straining 6·0% and Ageing. Tons per sq. in.
Molybdenum	.	.	.	2·0	3·27
Manganese	.	.	.	2·0	1·80
Chromium	.	.	.	1·15	0·82
Vanadium	.	.	.	0·55	0·02
Niobium	.	.	.	0·36	Nil
Titanium	.	.	.	0·21	Nil

In making comparisons of this kind the authors believe it is more reliable to consider the ultimate-stress results, as distinct from the yield-point values. The chief reason for this view is that the recorded values for the rise in the yield point as a result of strain-age-hardening are subject to greater experimental error than the corresponding ultimate-stress figures.

Whilst the authors appreciate the significance of Kuroda's views concerning the cause of the yield point in mild steel, they think that more definite evidence is needed before they can be accepted in their present form. The presence of a film such as he suggests has still to be proved. Further, it is necessary to demonstrate that a steel containing less carbon than is capable of being held in solid solution by ferrite will not show a yield point on the stress-strain diagram.

Before this aspect of the problem can be solved, much more exacting and carefully planned experiments will have to be made than have hitherto been carried out. Nevertheless, with comparatively small changes in Kuroda's conception, all its advantages might be retained without considering the presence of such a film. It is with these possibilities in mind that the authors, quite tentatively, put forward the following observations for future consideration :

(1) Carbon dissolved in ferrite will cause strain-age-hardening, and this is due to what is generally regarded as a special kind of precipitation of the carbon.

(2) This precipitation can be considered as something in the nature of a stage between a perfect solution and the separation of carbide of iron in the form of a distinct phase.

(3) The internal stresses set up in this way distort the crystal space-lattice and thus cause the material to be harder than it was before ageing

It may then be presumed that the extra resistance to plastic flow of the crystal boundaries, which gives rise to the yield point in ordinary ferrite, is due to the normal distortion associated with a change of orientation being accentuated by the presence of semi-precipitated carbide of iron in these regions. In other words, though the carbon content may be less than the accepted solubility limit in ferrite, the state of this carbon near the crystal boundaries may be much the same as that which prevails within the body of such crystals after

straining and ageing. This is merely suggesting that the inter-
atomic stresses near the crystal boundaries are such as to cause the
carbide to be in a condition of semi-precipitation in these regions in
annealed specimens. Some of the important facts which should be
remembered in this connection are :

(1) Pfeil [3] has shown that mild steel from which the whole of
the carbon has been removed does not display any capacity to
strain-age-harden.

(2) He found that this kind of hardening takes place when
the carbon content is not more than 0.003%, *i.e.*, less than can
be held in solid solution by ferrite at the ordinary atmospheric
temperature.

(3) It has been found that annealed steel from which all the
carbon has been removed does not show a yield point.

In the light of these facts and the evidence which has been re-
vealed in the present investigation concerning the influence of
titanium and other carbide-forming elements in causing steel to
become non-strain-age-hardening and in eliminating the yield point,
the problems under review become much clearer. The position may
be briefly summarised, as follows :

(*a*) The presence of small percentages of carbon, when associated
with iron (*i.e.*, not in combination with some other element), will
give rise to strain-age-hardening.

(*b*) The yield point, a characteristic of ordinary mild steel, is
not an intrinsic property of iron itself, but is due to the presence of
carbon.

(*c*) The effects of carbon, as regards both its influence upon
strain-age-hardening of mild steel and upon the yield point, can be
completely neutralised by the addition of elements for which carbon
has a greater chemical affinity than it has for iron.

(*d*) The function of titanium and other carbide-forming elements,
when introduced into steel in sufficient quantity, is to combine with
the whole of the carbon present, leaving none to be directly associ-
ated with the iron. The authors believe that these special carbides
are either insoluble in ferrite or incapable of being precipitated as
a result of straining and subsequent ageing ; in any case, there is
no carbide precipitation as a result of straining and ageing and,
therefore, no hardening can be produced by this treatment. Further,
if no carbon is dissolved in the ferrite, there can be no special
distortion of the space-lattice at and near the crystal boundaries.
Therefore the material behaves like most other pure metals and
non-ferrous alloys, namely, no yield point is observed on a tensile
stress-strain diagram.

(*e*) It is recognised that other elements besides carbon may have
the power of imparting strain-age-hardening qualities to mild steel,
and the same may be found to be the case for the yield point.

(*f*) In conclusion, it is perhaps necessary to mention that no detailed consideration has been given in the present work to the possible influence of oxygen and nitrogen. The authors recognise that interesting and important results may be obtained by extending the study to these two elements, and they look forward to the possibility of doing this. Nevertheless, they do not think the results will necessitate any material modification in the conclusions which have been arrived at in the present paper. It is true that most of the carbide-forming elements that have been considered also possess a strong affinity for oxygen, and many of them are believed to be capable of combining with, and possibly of removing, any nitrogen that may be present in liquid steel. That being so, the question arises whether the effects of these special carbide-forming elements are entirely due to their combining with carbon or also to their removal of, or combination with, oxygen and nitrogen.

The authors believe that the answer is provided by the results obtained with two of the titanium steels : The steel containing $0 \cdot 02\%$ of carbon and $0 \cdot 2\%$ of titanium had no yield point and did not strain-age-harden, but the specimen containing $0 \cdot 085\%$ of carbon displayed both these qualities to an extent which was comparable with steel containing no titanium. It seems reasonable to conclude that the absence of the yield point and strain-age-hardening in the former case cannot be attributed to the removal of oxygen and nitrogen, because it seems most probable that both these elements would be just as completely removed in the second sample as in the first. In other words, simply by raising the carbon content, the yield point and strain-age-hardening were made to reappear.

The only uncertain factor in this line of reasoning is the question whether the higher carbon content reduces the opportunity for titanium to combine with nitrogen. The question of oxygen is not so important in this connection, since it has been shown that samples with appreciable quantities of aluminium display normal strain-age-hardening, and they also show the ordinary yield point.

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DISCUSSION.

Professor J. H. ANDREW (Sheffield) said the authors had done an excellent piece of work and had provided much valuable data on strain-ageing. They had, he thought, shown very clearly that oxygen did not enter into strain-ageing in any way whatsoever, and also that carbon was essential for it.

He was particularly interested in the curve showing that aluminium increased the grain size and likewise the ageing of steel. In Sheffield many tons of non-ageing steel, treated with aluminium, and small-grain-size steel treated in the same way, were turned out every day. He took it, however, that the authors' annealing temperature was rather above that usually employed for this type of steel.

The authors explained age-hardening according to the American idea, that was, they assumed that it was due to the carbide being taken into solution during working, followed by precipitation of carbide after heating to 250° C. Dr. Lee and himself had been working on ageing from two points of view very closely associated. A low-carbon steel which had been quenched subcritically, *i.e.*, at about 700° C., gave a thermal heating curve showing two points; one was at about 100° C., which he regarded as being due to the formation of carbide of iron with absorption of heat, and was immediately followed at about 135° C. by an evolution of heat due to precipitation of carbide. At a temperature of 200° C. it was found that the whole of the carbide was precipitated. If, however, the steel was cold-worked instead, exactly the same changes took place as were obtained by quenching. If after cold-working the specimen was heated to 250° C. and then cooled, a marked expansion shown in a dilatation curve took place at about 125° C. Such an expansion was known to occur in steel that had become particularly austenitic, and the low-temperature change at 125° C. was usually regarded as being an austenitic-martensitic change. His view, therefore, was that the cold-work caused the carbon to go into solution, and on heating to 250° C. and cooling, the austenite-martensite transformation occurred. He therefore suggested that the authors were producing what might be regarded as a secondary hardening rather than a true ageing effect. If they had not heated the steels at all, but had allowed them to remain at atmospheric temperature, he thought they would have obtained even greater hardness increments due to both the precipitation effect and possibly the austenitic-martensitic change, which in time might take place at atmospheric temperature.

With regard to the question of the yield, the authors stated that a steel containing no carbon should show no yield; he would point out that Principal Edwards himself in 1926, in a paper written with Dr. Pfeil on single crystals, showed that the yield was largely a property depending on the crystal size. A single crystal gave no yield whatsoever, but when the number of crystals per square

millimetre attained a certain figure there was a very marked yield. He had confirmed this in his own experiments on carbonless iron. He was rather inclined to think the yield was a property of the α–γ transformation. When the authors added vanadium the yield disappeared, and he ventured to suggest that all pure α-steels and even α-irons (i.e., α at all temperatures) would show no yield, because the α–γ transformation was absent. It was possible, therefore, that the yield was very closely associated with the α–γ change. His remarks were in no sense a criticism. He simply put forward an alternative viewpoint, and, if Principal Edwards and his colleagues could use what he had said to substantiate their theory, so long as they arrived at sound scientific conclusions no one would be better pleased than himself.

Dr. T. SWINDEN (Member of Council, Stocksbridge) said all those interested in the subject of strain-ageing would be indebted to Principal Edwards and his colleagues for carrying out in such an able way the work described in the paper, but he would repeat the comment he had made on their earlier paper, namely, that the value of the data would be enhanced if the impact values had been included. The title of the paper referred to the influence of some special elements upon strain-ageing, and he would suggest that the thing that troubled one most was not the increase in strength—he did not see how one could worry very much about that—but the lack of ductility and particularly the reduction in impact value. When he read, in connection with the aluminium steels, that aluminium in varying degrees had little or no effect on the age-hardening properties, he was bound to say that that was entirely contrary to his own experience, in so far as strain-age embrittlement was concerned. A great deal of work had been published on that subject. He had shown [1] that with no aluminium added and a grain size of 3–4 the impact value fell from 92 to 6 ft.lb. after straining and ageing, whereas in the case of aluminium-treated steel, with a grain size of 7, treated in an exactly similar way, the impact fell only from 98 to 81 ft.lb. That, of course, was a common experience and applied to various types of steel.

The second point to which he would like to refer was the influence of titanium, a subject on which he had done a considerable amount of work and on which one or two papers had been written. There was no doubt that titanium formed a stable carbide, to the exclusion of iron carbide if there was sufficient titanium present. It was important to note, however, that the titanium carbide went into solution—rather slowly—if the steel were heated to a temperature in the region of 1050–1100° C. or higher. In a paper presented to the Institute of Welding [2] he had described a test made on a series

[1] *Transactions of the North East Coast Institution of Engineers and Shipbuilders,* 1938, vol. 54, p. 186.

[2] Swinden and Reeve, *Transactions of the Institute of Welding,* 1938, vol. 1, Jan., p. 7.

of steels with 0·25% of carbon, normal manganese and silicon, and titanium increasing from nil up to 1·6%. On quenching from 950° C., the hardnesses for that series of steels, with titanium respectively nil, 0·41, 0·76, 1·05 and 1·6%, were 413, 233, 209, 198 and 111. On going up to a higher temperature, 1250° C., the hardness values were respectively 364, 385, 308, 328 and 233, and, therefore, if one soaked the steel for a sufficiently long time at a high temperature one could get really high hardness values. Other interesting data were contained in a short article by Mr. J. A. Jones,[1] of the speaker's laboratory, in which, *inter alia*, the influence of titanium in suppressing *quench*-ageing was included.

He was very intrigued by the suggestion that in the absence of carbon there would be no definite yield point. Dr. Jay had sub-mitted a memorandum to him some time ago, advancing the same opinion, based upon his X-ray studies of cold-worked steels. He (Dr. Jay) would make a separate contribution, but meantime it might be said that a theoretical consideration of the problem indicated that an extremely small carbon content would satisfy the conditions under which a yield point would occur.

Dr. S. A. MAIN (Sheffield) said that some of the remarks he wished to make were a little critical, but he was sure they would be none the less acceptable to the authors.

The basis or standard material in this research seemed to be represented by No. 1 of the manganese series on p. 206 P, in which with carbon under 0·025% the manganese was 0·26%, copper 0·09% and nickel 0·09%. All the other alloys apparently had these elements in those proportions but with additions, either by increas-ing the percentage of manganese, copper or nickel or by the intro-duction of new elements like aluminium, molybdenum and chrom-ium. It seemed better, therefore, to compare the properties of all the various alloys in relation to those of this standard material.

On that basis, while, as stated in the paper, the addition of manganese progressively lowered the hardening measured by the ultimate stress, the hardening measured by the yield point was in every case higher in those alloys containing more manganese than the standard material.

Additions of molybdenum in each case increased the strain-age hardening measured in both ways.

These two carbide-forming elements therefore did not quite fit in with the rule.

In the case of aluminium, the addition of as little as 0·02% reduced in a very marked way the hardening as measured by the ultimate stress, and though after 0·25% there was a recovery with increased additions, the hardening did not quite reach that of the standard material. Against this, however, discounting small differ-ences, there was a progressive tendency downwards in the hardening

[1] *Metallurgist*, 1936, vol. 10, Oct. 30, p. 171.

as measured by the yield point. The evidence was therefore somewhat conflicting, but if maximum stress was the criterion, then it appeared that, after all, oxygen might be a factor favourable to strain-age-hardening. In other words, the first small additions of aluminium operated towards nullifying the effects of the oxygen, further additions showing the effect of the aluminium itself in promoting such hardening.

It might be questioned whether the true respective influences of the various elements on the hardening had been determined by the procedure adopted. It seemed likely that, when an element was added to the standard material, it might influence not only the rate at which the hardening proceeded at a specific temperature, but also the temperature at which there was the greatest hardening. Conceivably, therefore, other relations might have been found under a different ageing procedure, as regarded temperature and time, than that adopted, where the temperature was 250° and the time period, although not indicated, was doubtless the same for all.

In the various Tables the specimens were described as being fully annealed, but he wondered if that term could be justified in all cases. He mentioned this because the grain size of the steel with 3.4% of aluminium was not by any means as large as that with which he was acquainted in that ferritic type of steel in the annealed condition, where grains measured in millimetres rather than fractions of a millimetre were common. It was true that the steel with larger grains had higher carbon, about 0.05%, but this was not greatly in excess of the carbon in the authors' similar steel containing less than 0.025% of carbon. The point was important with regard to the other and non-ferritic types of steel and from the point of view of theory, namely, as to the possibility of there being some austenite remaining and ready to form martensite under strain-ageing conditions.

The theory of strain-age hardening was very intriguing, and we still seemed to be only groping towards the light. The authors appeared on p. 219 P to lean towards the idea of the carbon causing the hardening by some sort of separation of the carbide short of actual precipitation, but in other places seemed to picture it as being really precipitated.

In a paper [1] which he (the speaker) gave a year or two ago to the Sheffield Society of Engineers and Metallurgists, he tried to show that the temper-hardening of steel could not be explained by the precipitation of the carbide in discrete particles as the usual theories of precipitation hardening would have us believe. The idea there favoured was that the carbon entered structurally into the martensite which caused the hardening, and in a manner short of actual precipitation. The suggestion in the present paper that

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[1] S. A. Main, " Temper Hardening of Steel and a Theory of Tempering," *Metal Treatment*, 1938–39, vol. 4, Winter Issue, p. 158.

hardening might be caused by distortion of the space lattice by discrete particles of carbide was, he thought, inadequate.

It was a significant fact that the hardest martensite was found in plain carbon steels, and with the addition of carbide-forming elements other than iron the hardness obtainable diminished. Whether it was supposed that a sort of martensite was formed in strain-ageing, either from a ferritic or from an austenitic solution of carbon, it might not be too much to suppose further that those elements which, like aluminium, copper and nickel, did not react chemically with the carbon might be operating merely by easing, and rendering more rapid, the formation of this type of martensite. The carbide-forming elements, on the other hand, by their direct attachment to the carbon atoms, might seriously modify the nature and hardness of the martensite formed.

Dr. L. B. PFEIL (Birmingham) said that there were a large number of interesting results in the paper, but he would confine his remarks to the " Discussion of Results." He suggested that, if Principal Edwards and his colleagues adopted the view that the solid solubility of carbon in ferrite was very much lower than the literature indicated, a simplified explanation would be possible. If the solid solubility of carbon in ferrite was 0.001% at $250°$ C., which he thought probable, there would be no need to postulate the re-solution of carbon during the straining or the heterogeneous distribution of carbon within the ferrite crystals.

The effect of cold-work in accelerating precipitation-hardening was well known, and there seemed to be no reason why such an effect should not occur in the case of strained ferrite containing small quantities of carbon in solid solution.

With regard to the yield point, it was necessary to find some reason why the ferrite suddenly elongated under stress. The ferrite lattice distorted in a unique manner. There were, in effect, far more " planes " available for slip in ferrite than in other lattices. Thus, ferrite crystals would deform under stresses largely independent of orientation. It was necessary to explain, however, why ferrite in some forms should show a yield point and not in others. He suggested that, in its purer forms, the elastic limit of the ferrite crystal and of the more coarsely crystalline masses in which little support was obtained from the boundaries was so near to zero that no yield was observed. When the elastic limit was raised, in particular by the strengthening effects of precipitated carbide, well-marked yielding occurred at a substantial stress. Since all crystals deformed at practically the same stress, a well-defined yield point was readily measured. Such an explanation of the yield-point phenomenon required slipping to proceed at a lower stress than that necessary to initiate movement, for otherwise the work-hardening effects due to deformation would prevent the development of the yield " horizontal " on the stress-strain curve. He

suggested that the effect of titanium was to remove carbon from solid solution in the ferrite grains and so to eliminate precipitation-hardening and thus cause the yield point to disappear.

CORRESPONDENCE.

Dr. D. BINNIE (Irlam, near Manchester) wrote that, in keeping with the interesting tests made by Principal Edwards and his co-authors, a series of annealed commercial steels, mainly with varying carbon content, was tested and calculated in a manner similar to the tests made by the authors, except that a turned tensile test-piece, 0·564 in. in dia., was used. The carbon varied from 0·12% to 0·75%; also a hypereutectoid steel with 1·21% of carbon was selected.

TABLE A.

Steel.*	Carbon. %.	Manganese. %.	Ultimate Stress. Tons per sq. in.	General Elongation. %.	After Straining 6% and Ageing.		Increase in Ultimate Stress. Tons per sq. in.
					Ultimate Stress. Tons per sq. in.	General Elongation. %.	
A	0·12	0·43	27·2	37·5	30·8	24·0	3·6
B	0·15	0·56	29·1	35·5	32·8	24·0	3·7
C	0·18	0·65	30·0	35·0	33·6	23·0	3·6
D	0·28	0·71	34·4	30·0	37·2	21·0	2·8
E	0·75	0·45	50·8	13·5	54·2	12·0	3·4
F	1·21	0·32	41·6	26·5	44·4	25·0	2·8

* A to E, annealed; F, spheroidised.

The increase in ultimate stress, for a 6% strain followed by ageing at 250° C. for 1 hr., was much the same throughout the range of steels used, namely, 2·8–3·7 tons per sq. in. An increase of stress of 2·8 tons occurred when the hypereutectoid steel was tested with the carbide in a spheroidised condition. The hypereutectoid steel showed no age-hardening with the more limited amount of strain available when the structure was in a cellular condition, *i.e.*, having a grain boundary of cementite.

The results obtained were shown in Table A.

Principal Edwards' steels consisted almost entirely of ferrite. The series in Table A included a steel with very little free ferrite and the hardening due to ageing was much the same throughout. Therefore, the pearlitic ferrite must have been hardened to an extent similar to that of the free ferrite. Did this reconcile with the authors' theory of strain-ageing?

The theory of the cause of the yield point in mild steel put

forward by the authors did not include the directional nature of the yield point. A steel which had been strained in tension and aged had lost all trace of the original yield point when retested in tension, but nevertheless the position of this original yield point could still be deduced by subjecting the aged steel to compression or torsion.

The factors which accounted for the yield point were directional, and this would have to be borne in mind in any development of the theory of strain-age-hardening.

Dr. A. H. JAY (Stocksbridge, near Sheffield) wrote that in December, 1939, he completed a preliminary survey on the atomic structural changes in carbon steel during cold-deformation by the use of X-ray crystal-analysis methods.

The first tests were made on a heavily cold-drawn 0·8% carbon steel wire; a 0·5% carbon steel was also examined. X-ray photographs were taken, first on the surface layer, dia. 0·036 in., and then on wire of decreasing diameter obtained by etching. The photographs showed, in addition to a distorted α-iron phase, that the structure of cementite changed in passing across the section of the wire. This change in the cementite line pattern from that given by an annealed carbon steel reached a maximum at the centre of the wire. It was therefore inferred that the atomic structure of cementite was affected by cold-deformation and that the greater the deformation the greater was the change in the atomic structure. This inference was fully confirmed in similar tests on cold-rolled carbon-steel sheet, remembering that here the maximum deformation was in the surface layers of the sheet.

Tests were next made to determine at what point in the deformation process cementite suffered its first change. For this work annealed 0·8% carbon steel wire was used. A stressing frame was fixed on the X-ray tube platform and the wire subjected to a steadily increasing load. A long pointer served as an indicator of the extension of the wire specimen. X-ray photographs taken up to but not exceeding the yield point showed no structural changes. A photograph the exposure time of which included the yield-point " give " showed a definite change in the cementite pattern in addition to the expected breakdown of the α-iron crystals into smaller units. Photographs taken with higher loads showed a small but definite further change in the cementite pattern.

The following was taken from the original departmental memorandum :

Questions to be Answered.

(1) Is the yield point phenomenon characteristic of the α-iron phase or of the cementite ?

(2) If the α-iron phase is responsible, then why should a body-centred cubic structure behave in the well-known

manner of a carbon steel while a face-centred cubic structure, *e.g.*, copper, behaves quite differently ?

(3) If the cementite is responsible, then why should the value of Young's modulus of elasticity be the same within small limits for an annealed as for a cold-worked steel ?

In the first place we suggest that there is nothing in the atomic structure of α-iron that will create (*a*) an elastic range of, say, 10–20 tons per sq. in. for an annealed steel and (*b*) an apparently unstable condition at the yield point.

We then formulate the proposition that the elastic range and the condition up to the yield point are due to the cementite —let us say a cementite network in the boundary between the α-iron grains. (This does not mean that cementite cannot be in the grains.) Thus we regard the yield point as the point at which the cementite network breaks—a brittle break.

The sudden " give " of the test bar is due to the fact that, once the rigid cementite network has been broken, the load, now being carried more by the α-iron phase, quickly deforms the α-iron. In other words, the yield " give " is due to the sudden transfer of an overload on to the α-iron. The condition after the yield point is that further deformation causes increased breakdown of both α-iron and cementite.

This was the first occasion, to the writer's knowledge, on which X-ray crystal-analysis methods had been applied to this problem with special regard to the cementite structure. These results had been examined since in the light of earlier researches on the subject of the yield point and where the idea of a cementite network had already been put forward.

One of the many interesting points which emerged from this hypothesis of a three-dimensional cementite network around the α-iron grains was that only a very small amount of carbon was necessary to provide a complete crystalline carbide network. This was shown by the following calculations :

The material was divided into cubes of side L and each cube contained a slightly smaller cube, which was ferrite of side $(L - d)$. It was postulated that this ferrite cube was surrounded by a cementite network of thickness d.

Total volume $= NL^3$.
Ferrite volume $= N(L - d)^3$, where $N =$ number of cubes.

$$\therefore \ \frac{\text{Cementite}}{\text{Total volume}} = \frac{NL^3 - N(L - d)^3}{NL^3}$$

$$= \frac{3d}{L}, \text{ since } d \text{ was very small compared with } L.$$

The X-ray pattern of cementite indicated that the carbide was crystalline and it was reasonable to assume a value of $d = 100 \times$

10^{-8} cm., since this would be a minimum dimension which would satisfy a crystalline condition. With a grain (or crystal) size of the order of 1 mm., the ratio of cementite to total volume was given by :

$$\frac{3d}{L} = \frac{3 \times 100 \times 10^{-8}}{10^{-1}} = 3 \times 10^{-5}.$$

Now $\frac{V_{\text{cem.}}}{V_{\text{total}}} \sim \frac{V_{\text{cem.}}}{V_{\text{ferrite}}} = \frac{\text{Weight}_c/d_c}{\text{Weight}_f/d_f} \sim \frac{\text{Weight}_{\text{cem.}}}{\text{Weight}_{\text{ferrite}}}$, since $d_c = 7\cdot7$ and $d_f = 7\cdot8$.

Ratio of weights $= 3 \times 10^{-5}$.

$\therefore \frac{\text{Weight (carbon)}}{\text{Weight (ferrite)}} = \frac{(12)}{(180)} \times 3 \times 10^{-5} = 0\cdot2 \times 10^{-5}.$

$\therefore$ Carbon % (weight) $= 0\cdot0002\%$.

It thus followed that $0\cdot0002\%$ of carbon (by weight) satisfied a crystalline carbide skeleton for the above conditions.

The presentation of this paper by Principal Edwards led one to hope that the phenomenon of the yield point and its position in the load-extension diagram would soon be appreciated and fully understood. The further problem associated with the presence of a limit of proportionality, as distinct from the yield point, was now being examined.

Mr. D. A. OLIVER (Sheffield) wrote that this paper was of wider interest than merely in relation to the strain-ageing of low-carbon steels. The authors' careful experiments threw valuable light on the affinities of certain carbide-forming elements for what might be regarded as residual carbon contents in nearly pure iron. From that point of view it would be valuable if the authors could specify their carbon contents better than "under $0\cdot025\%$." That might be difficult if the carbon contents had been determined by the ordinary combustion method, which tended to give slightly low values. Might there not also be a possible $0\cdot01\%$ to add to the carbon figure quoted ? This was important in studying the amounts of different elements required to neutralise the effect of the carbon as summarised at the top of p. 219 P, as it was clear from the tabulation that many times more than the amount of the carbide-forming element was required than was estimated as necessary for combination with the specified maximum carbon.

In practically carbon-free permanent-magnet alloys of the nickel-aluminium-iron family, titanium had proved to be the most satisfactory element for combining with residual carbon, which in quantities exceeding $0\cdot06\%$ had the most deleterious effects on the magnetic properties. It was interesting to note that the authors also found titanium to be the most suitable element in their survey, as judged from its ability to neutralise the strain-ageing effect.

Regarding Table I., showing the effect of aluminium additions, it was noteworthy that the smallest crystal sizes were found associated with comparatively small contents of aluminium, whereas

larger sizes were found as the aluminium content increased. This was in accordance with large-scale experience in the grain-size control of steels by aluminium additions, and it was interesting that these characteristics were found in the small high-frequency casts made by the authors where large-scale experience was not usually borne out on small casts. This normally was due to the difficulty of precisely controlling the degree of oxidation to simulate large-scale practice.

AUTHORS' REPLY.

The AUTHORS wished to express their thanks to those who had taken part in the discussion.

In reply to Professor Andrew's remarks they felt that it was, at the outset, very necessary to clear up one point concerning their view of the cause of the hardening which occurred as a result of straining and ageing. Professor Andrew, at the beginning of his third paragraph, said that the authors " assumed that it [the hardening] was due to the carbide being taken into solution during working, followed by precipitation of carbide after heating to 250° C." This was certainly not the authors' view, and they found great difficulty in understanding why Professor Andrew made this assumption.

The authors' view was that with normal comparatively slow rates of cooling, ferrite was supersaturated with carbon or carbide of iron and that at all low temperatures there was practically no tendency for the excess of carbon or carbide of iron to separate from the ferrite, so long as the latter was not subjected to mechanical deformation. When, however, the ferrite was deformed, the super-saturated solution was rendered much more sensitive with regard to the precipitation of its excess of carbon. In the course of time at the ordinary temperature, but more rapidly at elevated tem-peratures, the semi-precipitation of carbon took place. In this connection the term " semi-precipitation " was intentionally used to differentiate it from the actual precipitation of particles of carbide of iron. In other words, the authors were inclined to think that the term " colloidal " precipitation of carbide of iron within the slip planes of iron would more adequately describe what they had in mind.

The authors were very interested in Professor Andrew's views concerning the connection between quench-age-hardening and strain-age-hardening. They would like to indicate what their views were at this point, and at the same time give an answer to part of Dr. Pfeil's contribution. For this purpose they would refer to Fig. A.

They considered that the solubility of carbon in α-iron, with normal slow rates of cooling, could be depicted by the curve ABC,

and that the diffusibility of carbon within ferrite over the range of temperature covered by AB was such as to permit the fairly rapid attainment of equilibrium. In other words, the experimentally determined values of the solubility of carbon in iron over this range of temperature were as near as possible correct. At temperatures below B, however, the diffusibility of carbon was so slow

Solubility Curve of Carbon in α-iron.
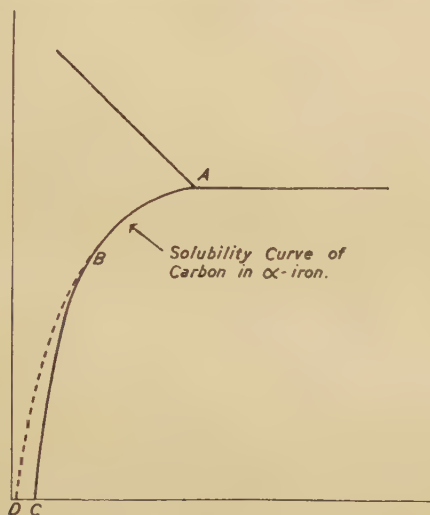
Fig. A.

and the atomic mobility of the mass so low as to prevent any possibility of equilibrium being reached under normal conditions of cooling. Therefore, from the point B to lower temperatures the experimental and theoretical curves departed from each other, the former being BC and the latter BD. From these considerations it followed that, in the case of all normally cooled steels, the ferrite would be supersaturated at ordinary temperatures.

If considerations of this kind were accepted, then the relationship between quench-age-hardening and strain-age-hardening could be easily seen, for there would be a close family relationship between them, as the hardening in each case would be due to the partial precipitation of carbon within the lattice. The intensity of hardening would, of course, be different, because the amount of carbon retained in solution by quenching would be much greater, and the tendency for precipitation after quenching would also be more pronounced.

In view of what Professor Andrew said about the yield point, and particularly with regard to his reference to the earlier work of Edwards and Pfeil, it seemed necessary to deal with this point. In the light of evidence obtained since the work of Edwards and

Pfeil in 1926, the authors had no hesitation in saying that the yield points referred to by Professor Andrew were due to the incomplete removal of carbon. There was no justification for suggesting, as Professor Andrew did, that the removal of the yield point by the methods referred to in the present work was due to the presence of rather large crystals. The authors believed that all the evidence went to indicate that the complete removal of carbon, or the prevention of carbon from being associated with iron by the addition of sufficient titanium, would eliminate the yield point.

Still another point in that connection was to be found in the observations for the aluminium series of steels, where specimens containing 3·4% of aluminium, which represented material that was α at all temperatures, gave very clearly-defined yield points.

In answer to Dr. Swinden, the authors felt it necessary to indicate at a little length the difference between the angles from which he and they regarded the problem. The authors' experiments had been limited to the study of the behaviour of their specimens with regard to strain-age-hardening as tested by ordinary tensile methods. They recognised the importance of impact tests from a practical point of view, and were in complete agreement with the stress laid by Dr. Swinden on this. They hoped to be able to extend their observations to an examination of the influence of the various elements on strain-age-embrittlement. Indeed, they had already endeavoured to take up this question with the specimens now under review, but had found that, with such low percentages of carbon present, the materials were so tough as to make it virtually impossible for them to differentiate between the effects of the various elements on the degree of strain-age-embrittlement.

The apparent anomaly between the facts referred to by Dr. Swinden concerning the influence of aluminium in diminishing the strain-age-embrittlement on the one hand, and the absence of such indication in the authors' tensile tests on the other, might be found to be due to the influence of oxygen in a steel containing no aluminium giving rise to embrittlement but to little or no change in the tensile tests. The authors would like to thank Dr. Swinden for the data that he gave relating to the effects of various quenching temperatures on the hardness of steels containing varying quantities of titanium. These were both interesting and significant from the point of view of the authors' work concerning the low, if not zero, solubility of titanium carbide in mild steel at ordinary temperatures.

The authors would like to express their great appreciation to Dr. Main for studying so carefully the evidence referred to in the paper and for his valuable criticism. They were ready to agree with him that oxygen, under certain special conditions, would contribute to the degree of strain-age-hardening which occurred in some of the materials used ; but they still felt that they were correct in concluding that carbon was the most important element

in this connection. It had been conclusively proved that in most instances the complete removal of oxygen from specimens containing a moderate amount of carbon did not materially affect the strain-age-hardening properties. On the other hand, the complete removal of carbon, or the neutralisation of that element by the addition of, say, titanium, prevented strain-age-hardening.

The authors agreed with Dr. Main in suggesting that in dealing with specimens of widely differing compositions the ageing temperature necessary to bring about the maximum amount of hardening might not necessarily be 250° C. Whether this was the case or not could be decided only by further independent investigation; but, as far as the authors' preliminary work was concerned, it seemed that not very much difference was obtained by ageing steels of widely differing compositions at temperatures between 250° and 350° C.

The authors were particularly pleased to have Dr. Pfeil's contribution. They had, in part, replied to this in their answer to Professor Andrew. From this it would be seen that Dr. Pfeil's views were in complete accord with the authors' so far as strain-age-hardening was concerned. There was, however, just one point which they would like to emphasise again in this connection, and that was that they presumed that Dr. Pfeil's reference to the unlikelihood of straining causing the re-solution of carbon was primarily intended to indicate that Professor Andrew's views concerning this were probably incorrect.

The authors were very interested in Dr. Pfeil's remarks regarding the yield point, but found some difficulty in deciding to what extent, if any, they differed from their own. They certainly agreed that, with a space lattice like that of ferrite, there were many planes upon which slipping could take place. They did not, however, consider it was at all likely that precipitation of carbon occurred upon any of these planes during the application of stress up to the elastic limit, and therefore they believed that the explanation which they had put forward was the most likely.

The authors would like to thank Dr. Binnie for his communication, which included some useful additional information bearing on the problem of strain-age-hardening. Whilst their own experiments had been almost entirely confined to specimens consisting largely of ferrite, they thought that the experimental results obtained by Dr. Binnie were in accord with their own. In other words, the ferrite in pearlite was evidently as capable of strain-age-hardening as massive ferrite. They were, of course, not in a position to indicate the quantitative relationship in this connection, but they felt that there were at least two factors which might cause the ferrite in Dr. Binnie's specimens to give a greater relative hardening of the ferrite for a specified degree of strain than when dealing with practically pure ferrite. These were: (a) The intensity of the cold-work in the ferrite of pearlite would, no doubt, be

greater for a given amount of tensile extension than would be the case when no carbon was present; and (b) the amount of carbon dissolved in ferrite was believed to increase within certain ranges of increase of carbon content, and this was also affected by the manganese content in the steels.

Speaking generally, therefore, the authors believed that Dr. Binnie's results were in conformity with their own. With regard to Dr. Binnie's remarks concerning the yield point, &c., the authors would like to say that they would keep these in mind in any future development of their work.

Turning to Dr. Jay's communication, the authors felt that they could say little more than express their pleasure that it went a long way in a new direction to support the views they had put forward. They hoped Dr. Jay would find it possible to extend his experimental observations along the extremely interesting lines upon which he had been working.

The authors were more than pleased to read Mr. Oliver's very interesting communication, and were gratified that he could apply the results contained in the paper to the special fields to which he referred. They would like to emphasise that it would be too much to expect the amount of any special element, such as titanium, required to combine with the carbon to coincide exactly with the chemical formula of the carbide that was formed. There must always be a kind of balanced reaction or distribution factor of the element introduced between that part which combined with the carbon and that which dissolved in the ferrite.

NON-METALLIC INCLUSIONS IN STEEL. QUANTITATIVE EVALUATION.—Part I.[1]

By W. H. HATFIELD, D.Met., F.R.S., and G. W. GILES, B.Sc.
(BROWN-FIRTH RESEARCH LABORATORIES, SHEFFIELD).

SUMMARY.

The authors have sought to evaluate the different factors influencing methods of inclusion counting. Experimental evidence is given which indicates the importance of the magnification selected for observation purposes, and it is shown that when examining a number of steels of different characteristics, if the standard magnification for the examination is modified, then the relative order of cleanliness becomes different. It is also shown that the comparison charts at present extant have not the quantitative value which has hitherto been attributed to them.

It is shown that, whilst the conditions of polishing materially influence the inclusion count as determined by methods at present in vogue, a light etching tends to establish what appears to be a more reliable basis for comparison.

The authors conclude by expressing their view, resulting from their researches, that until solutions have been found for the present disabilities, the present methods of quantitative estimation of the degree to which steels are contaminated by non-metallic inclusions are impracticable.

IT has always been an axiom that for consistency in performance steel should be as free as possible from non-metallic matter arising from whatever cause. This view has been accentuated of late years, owing to the increasingly high complex stresses which have to be resisted, as, for instance, in some of the modern aero-engine parts. That the tensile strength and the capacity for developing plastic deformation should be satisfactory in the longitudinal direction, when the test is coincident with the direction of rolling or hot-work of any other kind, may be vitiated in degree, if, owing to the orientation of the non-metallic matter, the tensile strength and/or the capacity for plastic deformation are adversely affected in the transverse direction. Since it is understood that for this and other reasons the steel should be as clean as possible, it follows that some quantitative method of measuring the cleanliness would be extremely valuable. Several methods have been devised, but as yet without success. This paper is submitted with a view to exploring the cause of failure of such methods, and contributing to the effort of

[1] Received September 4, 1940.

rendering possible quantitative comparisons of the relative cleanliness of different steels.

Quantitative comparison apart, there is generally little difficulty in obtaining general agreement between the producer and the consumer as to whether a given cast of steel meets the standard of cleanliness required by the consumer.

Non-metallic inclusions are essentially of two types :

    (*a*) Sulphides.
    (*b*) Oxides.

The amount of the former is controlled by the sulphur content of the steel ; the latter come into existence as oxidation products.

There is a third source, *i.e.*, the accidental inclusion of non-metallic matter from the refractories or from dust and dirt, but in these latter instances the resulting inclusions are of a nature distinct from those immediately under consideration.

When it is appreciated that in good open-hearth steel the total oxygen content is normally considered to be of the order of 0·006–0·009%, and that in electric-arc basic-hearth steel something of the order of 0·002–0·004%, it will be appreciated that if the sulphur content in the open-hearth steel is of the order of 0·03%, or in electric steel of the order of 0·01%, the amount of non-metallic matter arising from the sulphur is substantially greater than that which arises from the oxides.   Therefore, if it is desired to produce a really clean homogeneous steel, not only must the oxidation products entangled in the metal be kept as low as possible, but, even more important still, the sulphur content must be kept at the lowest level which is practicable.

It has been said that the slag inclusion count by a well-known method would, with a constant amount of non-metallic included matter from oxidation sources, give a consistently low inclusion count, *i.e.*, a high standard of cleanliness, although the sulphur content might be of the order of 0·04–0·05%.   It is obvious that in such a case the method failed to register the degree to which the steels in question were contaminated by non-metallic inclusions.   In such a case the method fails to register, within the arbitrary conditions laid down in the test, the amount of non-metallic matter existing in the form of sulphide.

A number of methods of quantitatively evaluating the non-metallic matter in steel have been put forward, and an Appendix of the literature on the subject is attached to this paper.   The three methods, however, to which the authors will confine their attention are the Jernkontoret, the Fox and the Firth-Brown methods.   Since the methods depend essentially on four factors these will be carefully considered on their merits, *i.e.* :

        (1) The selection of the sample in relation to the ingot ;
        (2) the preparation of the sample, with special reference

to the final preparation of the surface, which is a dominating factor;

(3) owing to the variable size in which inclusions of the same type or of different types may occur in the steel, the power of magnification is presumably a determining factor; and

(4) a critical examination of the charts purporting to represent the manner in which the inclusions occur in the steel, and to which a comparison of the actual occurrences of inclusions is referenced for quantitative purposes.

INFLUENCE OF TEST FACTORS DISCUSSED IN THE LIGHT OF THE AUTHORS' EXPERIMENTAL RESULTS.

Data concerning the steels upon which the authors' experiments were made will be found in Table I.

(1) *The Selection of the Sample.*

For a proper consideration of the distribution of non-metallic matter in steel, it is desirable to make reference to the large number of ingot sections to be found in the various Reports of the Heterogeneity of Steel Ingots Committee.[1]   In the early days of those researches the layout of the sulphide inclusions was clearly brought out by the sulphur prints, but in later Reports indication was given of the distribution of the silicates, as indicated by the oxygen content of the steel.   The main point arising is that steel ingots are indeed heterogeneous as regards the aspects under consideration, and, further, that the ultimate bar of steel which is examined must reflect or bear relation to, in cross-section, the heterogeneity existent in that portion of the ingot which it actually represents.   It has become customary to take the last ingot from the cast under examination.   This ingot is rolled into blooms, varying in size from 2 in. to 5 in. gothic, and 6-in. lengths are taken from the top, middle and bottom of the chilled portion of the ingot after the discards (amounting to about 20% at the top and 5% at the bottom) have been removed.   These three lengths are drawn down to $1\frac{3}{8}$-in. dia. bar, from which the micro-samples are taken.

(2) *The Preparation of the Samples.*

The method of preparation of a sample for inclusion counting varies widely in different laboratories.   The one adopted by the authors as being the most satisfactory for rapid routine preparation is as follows :

A disc $\frac{5}{8}$ in. thick was taken from the $1\frac{3}{8}$-in. dia. bar and cut in two to reveal the axis of the bar.   The sample was then hardened to facilitate polishing operations.   The surface examined was ground on an old and on a new 60 grit stone.   The scratches left by the

[1] Reports I. to IX., published at the Offices of the Iron and Steel Institute, 1926 to 1939.

TABLE I.—*Steels Used.*

Steel.	Cast No.	Description.	C. %.	Si. %.	Mn. %.	S. %.	P. %.	Cr. %.	Ni. %.	Mo. %.	O₂. %.	N₂. %.	H₂. %.	SiO₂. %.	Al₂O₃. %.
1	52313	Extremely clean electric steel.	0·14	0·19	0·30	0·010	0·012	Trace	5·26	...	0·0028	0·005	0·00014	...	...
2	66483	Clean electric steel.	0·31	0·17	0·62	0·008	0·008	0·91	3·76	0·24	0·0042	0·011	0·00011	0·0031	0·0058
3	10930	Characterised as commercial electric steel.	0·28	0·18	0·53	0·033	0·017	0·92	2·99	0·24	0·0038	0·009	0·00012	0·0056	0·0032
4	Z1823A	Characterised as very clean basic steel.	0·40	0·165	0·75	0·032	0·025	...	...	...	...	...	...	...	...
5	E6472	Characterised as commercial quality acid O.H. steel.	0·33	0·18	0·59	0·041	0·026	0·86	2·99	0·07	0·004	0·003	0·00012	0·0040	0·0048
6	19636	Characterised as clean acid O.H. steel.	0·33	0·28	0·78	0·022	0·022	0·83	3·51	...	0·0095	0·003	0·00013	0·0186	0·0080
7	19665	Characterised as clean acid Siemens steel.	0·31	0·21	0·54	0·022	0·022	0·78	3·61	...	0·0120	0·002	0·00007	0·0175	0·0025
8	W2255	Characterised as very clean acid steel but of high sulphur content.	0·33	0·25	0·64	0·048	0·033	0·26	3·06	...	0·0026	0·005	0·00012	0·0022	0·0059

Analysis.

smoother stone were removed on *IM* emery paper after the sample had been turned through an angle of 90°. The next operation was carried out either on 00 emery paper or on a slowly rotating (200 r.p.m.) cloth pad, to which coarse alumina had been applied in the form of a paste. The final polishing, which is the most critical operation, was done on a rotating disc covered with Melton cloth. This disc was moistened with water and sprinkled with a fine aluminous powder known as " Diamantine." The sample was not rotated during polishing, but was moved to and from the centre of the pad.

The function of this polishing operation is to remove the scratches left by the previous operation, and to leave the surface of the specimen in the best condition for examination. Depending on the abrasive, the polishing cloth, the pressure used and the steel which is being polished, the surface of the specimen is either " flowed," leaving a thin layer of metal in which the normal crystalline structure has been obliterated, or is cut cleanly away by the hard angular particles of the abrasive. A combination of the two may occur. If the pressure on the specimen is too light the scratches may not be removed completely, and there is a danger that the polishing material may be forced into the surface of the steel round the inclusions, making them appear larger. If too heavy a pressure is employed the surface will flow excessively and may become scorched, and the inclusions may be covered over or dug out.

It is not essential that a scratch-free surface is obtained as long as the scratches are at right angles to the direction of the inclusions and are not too deep to interfere with them. It has been found that a minimum of time on a wet polishing pad, using a very small quantity of abrasive, gives the best results.

Very interesting facts were brought out by Sir George Beilby concerning the possibility of the production by polishing of a film of indeterminate characteristics, claimed by him at the time to be amorphous. It will be interesting to consider the possible effects of the existence of such a film and its effect on some of the polished specimens under consideration.

(3) *The Influence of Magnification.*

A reference to the Bibliography in the Appendix will show that different earlier investigators [1] in this field have used different magnifications : H. Kjerrman, 200 diameters; Herty, Christopher and Stewart, 250 diameters; and Epstein, 100 diameters; whilst Kinzel and Crafts used 50 diameters.

[1] H. Kjerrman, *Jernkontorets Annaler*, 1929, vol. 113, p. 181.
    C. H. Herty, jun., C. F. Christopher and R. W. Stewart, *Mining and Metallurgical Investigations*, 1930, *Co-operative Bulletin No.* 38.
    S. Epstein, *Metals and Alloys*, 1931, vol. 2, Oct., p. 186.
    A. B. Kinzel and W. Crafts, *American Institute of Mining and Metallurgical Engineers*, 1931, *Technical Publication No.* 402.

Of all the methods which have been advocated for quantitatively evaluating the non-metallic matter in steel, that which is known as the Fox method is perhaps the most widely used, and may, therefore, be selected to illustrate the point which is now under consideration.   Bolsover [1] arbitrarily laid down that the magnification to be employed for the study of non-metallic matter should be 130 diameters.   To the authors' minds this always appeared to be a curious magnification to select, and would appear to have been arbitrarily determined by some local condition concerning the microscope employed.   In any consideration of the effect of magnification, the obvious thing to do was to take either the Fox evaluation charts or the Jernkontoret evaluation charts and evaluate the non-metallic matter at different magnifications.   The authors, therefore, proceeded to take standard micro-sections from the steels described in Table I. and to carry through the standard examination at 27·5, 132, 520, 1200 and 2000 diameters.   The inclusion " count " was taken with the specimens in the unetched condition, then again after very lightly etching with dilute picric acid (10 sec. approximately in 30% of a concentrated solution), this step being taken with a view to removing any Beilby film which might, by its existence, be preventing an accurate observation of the non-metallic matter present.

All the samples, except $Z1823A$ and $W2255$, which were received in the polished condition, were prepared in the manner already described.

The Leitz Panphot apparatus was used for the counting at magnifications of 27·5, 132, 520, 1200 and 2000 diameters.   It was considered preferable to use the visual tube of the microscope rather than the ground-glass screen, as by this means the chance of small inclusions being overlooked was reduced to a minimum.   It was not, therefore, possible to obtain magnifications of round figures.

The magnification of the microscope for any combination of objective and eye-piece is the product of the initial magnifications of the components used.   These are stated by the lens manufacturers and are the magnifications given by the lenses at a certain distance from the optical centre of the lens combination.   This distance is usually the tube length or bears a definite ratio to the tube length of the microscope.   The approximate figures given by the makers' constants were used.

Owing to the different combinations of eye-pieces and objectives used for the various magnifications, the apparent diameter of the field under examination varied from 88 mm. at 27·5 diameters to 260 mm. at a magnification of 2000.   These figures correspond to a standard distance of the visual image and were obtained by multiplying the diameter of the field subtended by the objective on the specimen, by the magnification.   At magnifications of 132 and 520, the fields were of a reasonable size—108 and 104 mm. in dia.,

[1] G. R. Bolsover, *Metallurgia*, 1935, vol. 12, July, p. 83.

respectively—but at 1200 and 2000 diameters they were too large to be conveniently examined or accurately compared with the Fox standard fields, which were 58 mm. in dia. Therefore, by means of a field diaphragm, the diameters of the fields were reduced to 108 and 110 mm.

It might not, at first, be considered that the field diameter could affect the count, but it must be realised that the counts are arrived at by comparison with standard fields. A large field containing, say, twenty well-distributed inclusions would tend to cause the observer to put the count higher than if a portion of the same field having half the diameter and a quarter of the area were graded. This field would contain five inclusions. Differences in the apparent fields used by different investigators have probably caused some of the variations in inclusion counts that have been noticed in the past.

To make sure that the same areas, as nearly as possible, were examined each time, two lines were scribed across the specimens from 3 to 5 mm. from each edge, and the counts taken on strips between these lines and as close to them as possible. Two runs were made across the samples at the $\times$ 27·5 and $\times$ 132 magnifications, but only one at the higher powers, with the result that about 24 fields were graded for each count at $\times$ 27·5 and about 450 fields at $\times$ 2000. These were totalled up, and the average field value was found. The figures reported in Table II. were reduced to a basis of 60 fields as in the normal Fox count.

It appeared quite likely that the polishing process might cover over some of the finer inclusions and result in a lower count than the actual cleanness of the steel justified. After the steel had been examined in the as-polished condition it was lightly etched in dilute picric acid in methylated spirit (30% of a saturated solution) until the surface was just clouding over. The specimen was then very lightly touched up on a clean polishing pad of Melton cloth. Marked increases in inclusion counts were obtained on some samples after the light etch.

The averaged results obtained are given in Table II. under lines A. Contrary to the expectation that the inclusion count would be higher on increasing the magnification, and that inclusions would be brought into view that could not previously be seen, the count shows a steady decrease as the magnification increases. This is attributed in part to the fact that the standard charts are not in accord with geometrical principles. Whilst the area of inclusion matter is small compared with the area of steel, for an increase in magnification, the inclusions are dispersed more widely, but in exactly the same proportion as the increase in size of the inclusions. It has been claimed that over a range the exact magnification used for the Fox count does not affect the result. In accordance with geometrical principles, this would be accepted, and one would anticipate that this statement could be extended over quite a large range of magnifications. Such a statement naturally assumes

TABLE II.—*Inclusion Counts.*

No.	Steel	Condition of Section		× 27·5	× 82	× 132	× 250	× 520	× 1200	× 2000
1	52313. "Extremely clean" electric arc basic hearth.	Unetched	A	5·5	...	13·0	...	7·6	7·8	6·0
			B	...	12·25	11·35	11·25	...	...	...
		Etched	A	17·0	11·0	17·0	8·0	9·0	6·7	5·5
			B	...	...	8·0	...	...	...	...
2	66488. "Clean" electric arc basic hearth.	Unetched	A	20·8	...	17·2	...	14·0	10·2	8·0
			B	...	20·9	18·3	20·3	...	...	...
		Etched	A	23·0	18·0	25·0	19·0	15·4	9·5	8·0
			B	...	...	18·0	...	...	...	...
3	10930. "Commercial" electric arc basic hearth.	Unetched	A	68	...	61·5	41	48	31·8	29·0
			B	...	35·5	36·2	...	...	...	...
		Etched	A	69	75·0	62·0	65·5	40·3	37·0	30·0
			B	...	...	70·0	...	...	...	...
4	Z1823A. "Very clean" basic open-hearth.	Unetched	A	11·4 (30)	...	32 (41·2)	...	24·6 (43·4)	23·3 (41)	17·1 (34·1)
			B	...	48·5	42·0	40	...	...	...
		Etched	A	67·0	56·0	68·0	...	49·5	45·0	33·8
			B	...	...	57·0	62	...	...	...
5	E6472. "Commercial" quality acid open-hearth.	Unetched	A	120	...	100·3	...	47·6	37·4	27·0
			B	...	82	71·0	61·5	...	...	...
		Etched	A	122	89	105·0	64·0	51·8	34·5	29·1
			B	...	...	85·5	...	...	...	...
6	19636. "Clean" acid open-hearth.	Unetched	A	102	...	79·2	...	47·0	33·4	27·0
			B	...	64·5	57·0	50	...	...	...
		Etched	A	68	92·0	75·0	71	41·0	35·0	30·1
			B	...	...	89·5	...	...	...	...
7	19665. "Clean" acid open-hearth.	Unetched	A	94·5	...	77·0	...	46·3	38·2	28·0
			B	...	56	52·5	52	...	...	...
		Etched	A	83·0	70	79·0	66	45·0	40·0	33·2
			B	...	...	74·0	...	...	...	...
8	W2255. "Very clean" acid steel, high sulphur.	Unetched	A	21 (60)	...	25 (67)	...	27 (53)	33 (42)	24 (37)
			B	...	58·0	46·0	50·7	...	...	...
		Etched	A	50 (58)	93·5	74 (72)	76·0	56·5 (50)	55 (48·5)	45·3 (38)
			B	...	...	76·0	...	...	...	...

that the charts for comparison would be such that this principle could be applied. That the charts depart from this principle is shown by the results of the counts at different magnifications, and the tendency for the counts to become less, the higher the magnification. This has been demonstrated in another manner :

Photographic reproductions have been made of some of the standard fields at a magnification of 4 diameters. These have been divided into fields of the same size as the originals, treated as samples for inclusion count, and graded against the Fox standards. A field of grade 2 gave a count of 11 for 16 fields or a total count of 41 on 60 fields, and a field of grade 3 gave a 24 count on 16 fields or 90 on 60 fields. These figures of 41 and 90 are quite different from the values of 120 and 180 that would be expected if the standards had been constructed geometrically.

As regards the counts at $\times$ 27·5, the inclusions were, in the majority of cases, very fine, besides being very numerous, so that only a very rough comparison could be made between them and the Fox chart.

It will be noticed that in some cases there is a decrease in count after the light etch. This is in most cases due to the plus or minus variations in the count that are normally expected when counts have been taken at different times. This may be partly due to the examination of a slightly different line on the specimen.

When the results had been considered, it was felt necessary to include figures for two intermediate values, and therefore the samples were *repolished* and examined at 82 and 250 diameters with a re-check on the values given for 130 diameters. This step led to important results and the figures are given in the lines marked B in Table II., both as polished and as subsequently lightly etched. This work, it must be remembered, was carried out by the same investigator and with great care, but a different order of counts was obtained in the polished condition.

Take, for instance, steel No. 3 (10930). On repolishing a count of 61–62 became a count of 37–35·6. These effects are apparently due to a new polishing cloth, and, although two days were spent in trying to get the cloth into condition, the results were as indicated. Maybe the condition of the cloth was conducive to the production of the Beilby layer and the obscuration of certain inclusions.

(4) *Critical Examination of the Quantitative Validity of the Comparison Charts.*

In this connection a quantitative examination of the Jernkontoret chart [1] and the Fox chart [2] was made, the object of this quantita-

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[1] B. Rinman, H. Kjerrman and B. Kjerrman, " Inclusion Chart for the Estimation of Slag Inclusions in Steel." Uppsala, 1936 : Almquist and Wiksells Boktryckeri A.-B.

[2] G. R. Bolsover, *loc. cit.* The actual experimental work was carried out on a chart issued by Samuel Fox and Co., Ltd., with a brochure entitled " The ' Fox ' Inclusion Count."

tive study being to determine whether or not the quantities of inclusions represented on these charts were present in the different grades in the ratios which are given, *i.e.*, 1, 2, 3, 4, 5 or 1, 2, 3, 4, since these ratios are quantitatively reflected in the inclusion count.

Images of the various grades were projected on to a screen, and the outline of the inclusions was drawn on paper placed on the screen. Pieces of paper of the size of the inclusions were cut out and weighed, the weight being proportional to the area of inclusion matter present.

There are forty diagrams in the Jernkontoret chart. These are divided into five different grades, with eight standard fields in each grade. These represent four types of inclusion :

> *A*.—Sulphide.
> *B*.—Aluminium oxide.
> *C*.—Silicates.
> *D*.—Certain oxides.

Two examples are given in each inclusion type, the inclusions in one being of a different thickness from the others. These thicknesses are represented by the letter μ and are only arbitrary examples. The results, which are given in Table III., show wide variations.

The figures given are actually weights in grammes, but are proportional to the areas of inclusions present in the standard charts.

TABLE III.—*Jernkontoret Chart.*

Grade.	*A.*		*B.*		*C.*		*D.*	
	4μ.	6μ.	9μ.	15μ.	5μ.	9μ.	8μ.	12μ.
1	0·0232	0·0260	0·0112	0·0293	0·0206	0·0281	0·0119	0·0258
2	0·0534	0·0826	0·0330	0·1000	0·0454	0·0636	0·0340	0·0859
3	0·1280	0·1930	0·0900	0·2730	0·0791	0·1120	0·0634	0·1338
4	0·2673	0·3700	0·1653	0·4594	0·1471	0·1969	0·0874	0·2462
5	0·4060	0·6226	0·3769	1·1790	0·2848	0·3782	0·1528	0·3145

It has been found by this method of measuring the areas of the inclusions in the standard fields of the Fox chart (Table IV.) that the average area of inclusion matter in each of the four grades, instead of being in the ratio of 1 : 2 : 3 : 4 as would be expected, is in the ratio 1 : 2·15 : 6·83 : 15·0. Even so this quantitative aspect is only two- instead of three-dimensional.

Figures have been worked out for twenty selected electric and twenty selected open-hearth casts of steel on this basis. The electric-steel casts were specially selected in that they contained No. 2 and No. 3 fields (and an occasional No. 4). A far greater number of casts contained only fields of grade 1 or not more than three fields of

TABLE IV.—*Fox Chart.*

Grade :	1.	2.	3.	4.
(a)	0·086	0·23	0·87	1·27
(b)	0·136	0·38	0·90	3·01
(c)	0·15	0·19	0·77	1·32

grade 2 and were not included. In this greater number of cases, the new basis for count would not alter the count figure.

The old and new results for the electric and open-hearth casts are given in Table V.

TABLE V.—*Old and New Counts on Electric and Open-Hearth Steels.*

Electric Steel.				Siemens Steel.			
Cast No.	Count.			Cast No.	Count.		
	Old Fox Basis.	New Basis.	Increase.		Old Fox Basis.	New Basis.	Increase.
53629	35	51	16	19147	116	146	30
60519	65	78	13	19196	110	131	21
62121	45	54	9	19200	128	167	39
64726	57	66	9	19228	118	141	23
65799	48	57	9	19255	108	115	7
66920	56	61	5	19322	82	93	11
67009	46	47	1	19334	90	94	4
67084	37	45	8	19351	100	113	13
67110	49	69	20	19405	122	160	38
67129	40	44	4	19407	94	121	27
				19427	91	96	5
67140	39	50	11	19458	90	95	5
67191	45	57	12	19501	100	120	20
67383	63	79	16	19502	118	155	37
67528	57	69	12	19511	86	90	4
67657	64	66	2	19517	114	130	16
67684	150	269	119	19535	124	197	73
68176	51	52	1	19879B	91	104	13
68202	40	44	4	19879W	104	119	15
68350	51	51	0	19908	112	123	11
68443	84	88	4				

It will be seen that the non-quantitative nature of the reference chart, if used in a quantitative manner, as is practised, leads to an erroneous gradation of the steels as regards cleanliness.

CONSIDERATION OF THE RESULTS.

For a proper consideration of the results disclosed in Table II. it is necessary to study each steel in detail.

Steel No. 1, *Cast No.* 52313, was included as representing perhaps the cleanest steel that the authors had ever examined. It was manufactured in the arc furnace on a basic hearth in their own works. It is a 5% nickel case-hardening steel; the sulphur content is 0·010%, and the oxygen content 0·0028%.

Steel No. 2, *Cast No.* 66483, is an electric-arc steel made on a basic bottom. It is a nickel-chromium-molybdenum steel, regarded as quite clean by the Ingot Committee, and adopted by them for comparative mechanical test purposes. It has a sulphur content of 0·008%, with an oxygen content of 0·0042%. This was made in the authors' own works.

Steel No. 3, *Cast No.* 10930, is an example of an electric-arc steel made on a basic hearth, which was bought in the open market as representative of commercial practice. It is a nickel-chromium-molybdenum steel, and the suppliers delivered the billets from stock. The sulphur content is 0·033% and the oxygen content 0·0038%.

Steel No. 4, *Cast No.* Z1823A, is an example of basic open-hearth steel, considered to be " very clean." The sulphur content will be noted as 0·032%. This sample was supplied by another company. In this case the material is simply a carbon steel.

Steel No. 5, *Cast No.* E6472, was supplied from billets in stock by another firm, as representing commercial-quality acid open-hearth steel. This is a nickel-chromium-molybdenum steel; the sulphur content is 0·041%, but the oxygen content is only 0·004%.

Steels Nos. 6 *and* 7, *Casts Nos.* 19636 *and* 19665, are representative of acid open-hearth steel of high standard, produced according to a long-established practice in the authors' own works. These two materials are nickel-chromium steels; in both cases the sulphur content is 0·022%, and the oxygen contents are 0·0095% and 0·012%, respectively.

Steel No. 8, *Cast No.* W2255, is another acid Siemens steel, produced in another works, which was considered to be an instance of very clean steel, in spite of the high sulphur content. This material is a 3% nickel steel; the sulphur content is 0·048%, and the oxygen content very low at 0·0026%.

This set of steels constitutes an extremely interesting series, and the figures obtained in the form of inclusion counts require to be studied in great detail. The results obtained by the authors indicate once more that generally any piece of painstaking research tends to yield some new and interesting aspect.

The examination of steel No. 8, cast No. *W*2255, was particularly instructive. The sample was first of all counted as received and counts of a very low order were obtained (25 at 132 diameters), and in this instance the low count seemed to be independent of the magnification. The light etching, however, immediately increased the count to a value similar to that obtained from the other acid

Siemens steels. The surface of the specimen was, therefore, re-prepared and again counted in the polished condition, when, as will be seen, much higher values were obtained, but, on etching, practically the same value was obtained as on etching the sample as received. The figures in brackets were obtained with the speci-men as received and are counts obtained by the authors after a preliminary re-polish. In the same connection, the results from steel No. 3, cast No. 10930, are worth studying, since the second time the specimen was prepared a count of little more than half the value representing the condition as first prepared was obtained, whilst after the light etching the results came substantially into line.

The authors do not propose to discuss all the figures from each steel in detail, but would ask readers to refer to Table II.

As the magnification increases above 80 diameters, there is a tendency for the inclusion count to decrease. At 27·5 diameters the results are somewhat variable, owing to the inclusions appearing very small at this magnification, and the difficulty in accurately comparing a large number of extremely fine inclusions with a chart containing about twelve larger ones.

Etching the samples results in an increase in the inclusion counts in most cases. This is particularly noticeable in casts Nos. $Z1823A$ and $W2255$, in which the inclusions are very small sulphides, such as may easily be covered over by the polishing operation if care is not taken. That this effect can be reproduced by very heavy polishing on a new cloth is shown markedly by the B counts on casts Nos. 10930, 19636, 19665 and $W2255$, at the magnifications of 82, 132 and 250 diameters. In each case the counts fall in line with the others after lightly etching.

There are cases where the count after etching is a little lower than that beforehand, and where there are variations in counts at a given magnification of the order of 10%. This is due to the usual margin of error allowed in this count when the readings are taken at different times or by different people.

The count of 102 for cast No. 19636 at 27·5 diameters may seem rather high when compared with the figure of 68 obtained after etching. This magnification is too low for the accurate counting of small inclusions, it being very difficult to distinguish the in-clusions from polishing imperfections, which latter are not noticeable after etching, and can be recognised at greater magnifications if they are visible. If attempts were made to remove these imperfections by further polishing, there would be a risk that some of the inclusions might be obscured.

The effect of the magnification on the order of cleanness of the casts is remarkable. Apart from the very clean steels Nos. 52313 and 66483, cast No. $W2255$ heads the list as cleanest at 27·5 diameters. As the very fine inclusions become visible at the higher magnifica-tions, its position in the list sinks, until it is the dirtiest steel at 250 diameters and over. Cast No. $Z1823A$, which contains similar

inclusions, maintains its high position in the list up to 520 diameters, when it is the third from the bottom, sinking to the bottom but one at 1200 and 2000 diameters.   On the other hand, cast No. *E*6472 progresses from the dirtiest cast at 27·5 diameters, and at the standard magnification of $\times$ 132, to the third cleanest at 1200 and 2000 diameters.

This can be summed up by saying that as the magnification increases, the steels which are lowest on the list at the beginning gradually " improve " in cleanness and the " cleaner " steels grow gradually " dirtier."

Conclusions.

The practical object of this investigation was to assess this very interesting series of steels from the standpoint of cleanliness, *i.e.*, relative freedom from non-metallic matter.   It will be seen that steels Nos. 1 and 2 appear to stand out, as far as can be ascertained by this line of attack, as very clean steels.   The interesting conclusion, however, at which the authors invariably arrive is that as regards steels Nos. 4, 5, 6, 7 and 8, there is very little distinction in the degree of cleanliness.

The prime object of inclusion counting is to obtain a quantitative valuation of the relative cleanliness of one steel compared with another.   It has been claimed that if the procedure in counting is uniform several investigators will obtain the same values, and this, within limits, is agreed.   But, if the method is based upon intrinsic fallacies and on non-quantitative data, reasonable agreement on the figures arrived at is none the less of little value in assessing the relative cleanliness.

The standard charts are not sufficiently varied in regard to types of inclusions, and whilst the ratio of the count values of the fields in the different grades are 1, 2, 3 and 4, the areas of inclusion matter given are in quite different proportions.

Large inclusions may cover as many as six fields vertically, and whereas only one, or at the most two, such fields would be counted by the method, the steel would instantly be rejected by most users, without any indication being given in the count.

The present method of inclusion counting is misleading in the interpretation that it gives of the amount and nature of the non-metallic matter.   With certain steels, if the specimen is lightly etched to remove the Beilby layer which obscures the non-metallic matter, the materials may be placed in an entirely different order of cleanness, and some steels which had been classed as clean could be characterised as dirty.   This effect is particularly noticeable where the inclusions are very fine sulphides which have undergone a great deal of elongation by rolling.

By altering the magnification at which the inclusion count is taken, the relative grading of the cleanliness of the steels is completely modified, and there seems to have been little justification

for the magnification arbitrarily chosen by the sponsors of the test.

The standard charts are not on a satisfactory quantitative basis.

Some time ago the authors devised a modification in the method of counting to take care of the difficulty that the count at the outside of the bar was representative of a far greater volume of steel than a count at the centre. In the Firth-Brown count, therefore, a diametrical cross-section of the bar was divided into ten zones, numbered $E1$, $D1$, $C1$, $B1$, $A1$, $A2$, $B2$, $C2$, $D2$, $E2$. About four fields were examined in each of these zones, and graded according to the Fox chart. The average cleanliness of each zone was calculated and multiplied by its " volume factor "; these were 1, 3, 5, 7 and 9, for the zones A to E, respectively. The total of these products was divided by 100, and the result expressed in the form of an " average field " with regard to the Fox chart. This method fell into disuse on the grounds that it was too complicated and that the advantage obtained through the introduction of the " volume factor " was outweighed by the inaccuracy in grading, due to the method of grading employed, which was subject to the same disadvantages as was the Fox method.

It is indeed difficult to see what lines can best be followed to produce a method which will give reliable quantitative indications of cleanliness, but the authors hope that this account of their own efforts to explore existing methods will at any rate have pointed out some of the disabilities which have to be overcome.

The field of study is an extensive one, since not only would it be of value to have some quantitative method of determining the amount of non-metallic matter present, but it is also important to evaluate the influence of the different types of inclusions upon the characteristics of the steel.

APPENDIX.—*History of the Attempt to Count and Evaluate Inclusions.*

Steel Treating Practice. R. H. Sherry. (New York and London, 1929 : McGraw Hill Book Co., Inc.). The author states (p. 224) : " The amount of dirt that can be permitted depends upon the service required of the steel, and for much service a considerable quantity of dirt can be permitted. Manganese sulphide and other inclusions improve machinability and are not necessarily harmful. Much depends upon the size and shape of the particles. Tiny globules scattered uniformly can do little harm, but inclusions in streaks may cause trouble. For important parts, too much dirt is undesirable, but the complete removal of inclusions from steel is impossible and unnecessary. Some will always be present. Inspection must draw a line of acceptance and rejection for kind and quantity." A satisfactory standard that provides facts rather than argument is illustrated by a series of photomicrographs arranged in order of increasing inclusion content, the maximum allowable for the particular service for which the steel is to be used being indicated. In practice such a series would include more examples, and rejection would depend upon the general condition rather than upon a definite comparison. Similarly, a series for included oxides is shown.

A Method for the Determination of Slag Inclusions in Iron and Steel. H. Kjerrman. (Jernkontorets Annaler, 1929, vol. 113, pp. 181–199). The

author examined definite-sized fields with a micrometer ocular, several fields from one specimen, and expressed his results as the number of inclusions per sq. mm., the average size of the inclusions and the maximum size.   He used a magnification of about 200 and counted all the inclusions down to those 0·002 mm. in size.   He frequently separated the inclusions into two groups— the silicates and the sulphides.   He noticed that the inclusions appeared smaller as the bars were reduced to smaller sizes in rolling and, therefore, used longitudinal sections of the same size of bar, ⅝ in. square, in all of his work.   His specimens were taken from the middle of the middle ingot of the heat.

Non-Metallic Inclusions in Iron and Steel.   C. Benedicks and H. Löfquist. (First Edition.   London, 1930 : Chapman and Hall, Ltd.).   On p. 193 it is stated that the slag grains visible under the microscope may be counted and their size estimated, or a simple comparison may be made between the specimen and arbitrarily chosen standards.   Based upon this comparison, a certain slag number is then allotted to the material.   An example of such a standard scale is given, showing ten different grades.   In many cases a smaller number has, however, been considered sufficient.   Both procedures are approximate, and to furnish adequate results tests must be made at several points on a specimen.   Moreover, the results depend to a very large degree upon the discrimination of the observer.

The Physical Chemistry of Steelmaking : Deoxidation with Silicon in the Basic Open-Hearth Process.   C. H. Herty, jun., C. F. Christopher and R. W. Stewart.   (Mining and Metallurgical Investigations, 1930, Co-operative Bulletin No. 38, pp. 25–29).   The authors were interested in the amount of non-metallic inclusions in small ladle test samples of experimental melts and did not extend their method to the rolled material from large commercial heats.   They used a micrometer ocular at a magnification of 250 diameters and surveyed thin strips of a given area of the section through the casting from the centre to the outer edge for inclusions, segregated them into various sizes according to their diameter, and then calculated the weight percentage of non-metallic matter.   In the small ladle test ingots the inclusions were very small ; evidently all that were resolved at the magnification used were counted.

Inclusions and their Effect on Impact Strength of Steel.   A. B. Kinzel and W. Crafts.   (American Institute of Mining and Metallurgical Engineers, 1931, Technical Publication No. 402).   The authors state that " the present commercial rating of inclusions is unreliable."   In the method that they devised, they photographed a number of representative fields of longitudinal sections of 2-in. round and square bars at a magnification of 50 diameters.   The negatives were then enlarged by projection and the lengths of the inclusions measured.   They counted all inclusions down to a size of 0·005 mm. and expressed their results as the number of inclusions of a given size per square millimetre and as a " total length figure," i.e., the sum of the lengths of all of the inclusions per square millimetre, as if they were placed end to end.

A Suggested Method of Determining the Cleanness of a Heat of Steel.   S. Epstein.   (Metals and Alloys, 1931, vol. 2, Oct., pp. 186–191).   After reviewing the inclusion-count methods of Kjerrman, Herty, and Kinzel and Crafts for the determination of inclusions in steel, the author describes a proposed method and presents the results obtained.   The method was developed at the works of the Illinois Steel Co.   The minimum number of samples taken from a heat was nine, these being from the top, middle and bottom billets of the first, middle and last ingots.   A polished specimen was used of longitudinal section, ½ sq. in. in area, through the axis of a 2-in. round extending ½ in. along the length of the bar, and from the centre to the outer surface. The inclusions were measured with a micrometer ocular and recorded.   The magnification used was 100 diameters.   The inclusions were classified into five groups : Small, medium, large, double large and triple large, the " weights " given to these being 0, 1, 2, 4 and 6, respectively.   No attempt was made to express the results in terms of absolute values, such as the area or number of inclusions per unit area.   Instead, a simple number was assigned to each specimen, this being derived by adding the " weights " of all the inclusions

found. The sum of these numbers from all of the specimens of a heat divided by the number of specimens was then used as the index number of cleanliness of the heat of steel.

Non-Metallic Inclusions in Steel, their Distribution and the Influence on them of Deoxidising Agents, especially Zirconium, Sodium and Calcium. W. Zieler. (Archiv für das Eisenhüttenwesen, 1931–1932, vol. 5, pp. 299–314). A method of estimating the number and size of non-metallic inclusions is described, in which sections cut from various parts of an ingot are examined microscopically and the number of inclusions per unit area is counted. Over a hundred electric-furnace melts were examined in this way. It was concluded that silicate and oxide inclusions are most numerous in the foot of the ingot, and also the largest inclusions are found there. Sulphide inclusions follow the segregation in the ingot and are, therefore, most numerous in the head of the ingot. The most important types of inclusion are mentioned, and also the process of freezing and its influence on the inclusions are explained.

The Present State of Methods for Determining Oxygen and Oxides in Iron and Steel. R. Castro and A. Portevin. (Revue de Métallurgie, Mémoires, 1932, vol. 29, pp. 414–421, 449–469, 492–506, 553–564). A critical study was made of the various methods for determining oxygen and oxides in iron and steel. A bibliography of 231 references is given.

Microscopic Studies on Slag Inclusions in Iron and Steel. H. Löfquist. (Jernkontorets Annaler, 1933, vol. 117, pp. 49–111). The author has carried out a microscopical investigation of the slag inclusions occurring in a number of steel samples representing different qualities of open-hearth, converter and electric steel, and also in specimens of wrought iron. The inclusions were in most cases identified by etching, but in several cases the slag inclusions were identified by comparison with synthetically produced substances. Manganese-iron spinel (($Mn,Fe)O.Al_2O_3$), mullite ($3Al_2O_3.2SiO_2$), chromium sulphide (CrS), and CrS–CrO eutectic were identified as slag inclusions in steel for the first time. Vanadium nitride (VN) was also found in cases where no vanadium addition had been made and which originated from the vanadium content of the sponge iron used. In chromium and some other alloy steels a few new slag inclusions were identified. It was found that all the common slag occurrences observed could be classified into a certain number (say, 14) of different slag types. By means of a slag diagram it was found possible to represent all the oxide and sulphide-oxide inclusions common in plain carbon steels so as to elucidate their mutual relations. This diagram also shows the difference between the slag contents of acid and basic steel, as well as the effect of killing with aluminium. A steel diagram analogous to the slag diagram was constructed so that each steel is represented by a point giving the proportions between its silicon and manganese contents and the added aluminium. By comparing the two diagrams it was found that for a given steel the relation between the silicon and manganese contents and the added aluminium practically determines its slag type. The condition necessary for this relation to hold true is that in all cases equilibrium must practically prevail between the steel and the slag, a fact which could not be presupposed *a priori*.

Non-Metallic Inclusions in Steel. G. R. Bolsover. (Metallurgia, 1935, vol. 12, July, pp. 83–84). In this article the author describes a method adopted by him, known as the inclusion count. For examination purposes, representation of the complete ingot section is obtained by taking a sample from the top, middle and bottom of the ingot ; each sample is forged or rolled into a bar 1⅜ in. in dia., which is cut longitudinally through the axis of the bar. The sawn face is then prepared for micro-examination. Examination from edge to edge of the specimen—*i.e.*, across the axis—gives a picture representing a complete cross-section through the axis of the ingot, and in order to minimise any possible discrepancy by the examination of a single plane the sample is examined on two such lines. By the adoption of a standard magnification of 130 diameters, a complete traverse of the section involves approximately thirty fields, this number having been taken as a standard. The examination of two different lines, as just described, results

in the inspection of sixty fields for each specimen or sample. In order to establish a quantitative basis for the correlation of the various results, a set of micrographs has been prepared, representative of the range of inclusion groups found in steel of various types, and these micrographs have been graded 1 to 4 in increasing order of severity of non-metallic matter content. Of the sixty fields examined, the number of fields corresponding with each grade is multiplied by the grade number, and the sum of the products of all the fields is adopted as the inclusion number for the sample of steel examined.

Observations on the Detector Action of Non-Metallic Inclusions in Steel. J. Czochralski and W. Sznuk. (Wiadomości Instytutu Metallurgii i Metaloznawstwa, 1936, vol. 3, No. 1, pp. 3–4). By means of a " radio-microscope," the detector powers of various types of non-metallic inclusions in steel were tested. A very weak detector action was found for iron and iron-manganese silicates, but owing to the extremely small dimensions in which inclusions occur in steel and the unknown effect of various factors, this method is not used for the identification of silicates.

Determination of Non-Metallic Inclusions on the Surface of Polished Metal Specimens. J. Czochralski and W. Sznuk. (Wiadomości Instytutu Metallurgii i Metaloznawstwa, 1936, vol. 3, No. 1, pp. 5–6). Differences in the electrical resistance of non-metallic inclusions in metals were used as an objective method of determination. A sharply pointed needle was moved to and fro across a polished steel surface, and the deflections shown by a milliammeter connected to the needle, the specimen and a 4-V. accumulator (through a resistance) were observed. Each decrease of the current was found to be related to a defect, the size of which varied with the extent of the deflection. Inclusions smaller than about 0·1 mm. in dia. could not be detected by this method.

A Scale for the Estimation of Slag Inclusions in Iron and Steel. B. Rinman, H. Kjerrman and B. Kjerrman. (Jernkontorets Annaler, 1936, vol. 120, pp. 199–225). The article describes a scale for the estimation of slag inclusions in iron and steel, which is standard in Sweden. This scale consists of a series of micrographs, designed to show different typical fields of view, and arranged in groups according to the form and distribution of the inclusions and numbered according to their quantity. In the practical application, the appearance of the specimen under the microscope is compared with the micrographs in the scale.

Inclusion Chart for the Estimation of Slag Inclusions in Steel. B. Rinman, H. Kjerrman and B. Kjerrman. (Uppsala, 1936 : Almquist and Wiksells Boktryckeri A.-B.). A publication in English describing and giving instructions for the use of the standard scale referred to in the preceding abstract.

A New Recording Microphotometer and its Application to the Quantitative Estimation of Non-Metallic Inclusions. M. Smialowski. (Wiadomości Instytutu Metallurgii i Metaloznawstwa, 1936, vol. 3, No. 1, pp. 45–55). An apparatus, comprising a small metallographic microscope, a selenium photoelectric cell, a light source, a galvanometer and a registering drum, is described, by means of which the reflectivity of a very small area of a specimen can be measured. The specimen is moved to and fro and forward at the same time, so that a certain area is " covered." Examples of the use of the apparatus for determining non-metallic inclusions in steel, pearlite in carbon steel, graphite in cast iron and the average linear crystal size in a bearing metal are given.

Determining Clean Steel. " Fox " Inclusion Count Method. (Iron and Coal Trades Review, 1936, vol. 133, p. 45). A description of the system devised by G. R. Bolsover (*see* above).

Chart for the Estimation of Inclusions in Steel. (Metal Treatment, 1936, vol. 2, Winter Issue, pp. 190–193). Particulars are given of the chart and method used for estimating the slag inclusions in rolled or forged steel, as described by B. Rinman, H. Kjerrman and B. Kjerrman (*see* a preceding abstract).

Evaluation of Steels for Roller Bearings by their Slag Inclusions. H. Diergarten. (Archiv für das Eisenhüttenwesen, 1936–1937, vol. 10, pp. 197–204). Photographs of slag inclusions in steels used for roller bearings

are given to show how such steels may be classified as regards their quality. The type and distribution of the inclusions determine this classification. The inclusions may consist of sulphide slags, brittle oxide slags and semi-plastic oxide slags in a spherical, oval or streaky form; examples of all these in varying proportions are illustrated.

The Relation between Non-Metallic Inclusions, the Size of Steel Grain and Abnormality in Structure. K. Kovraiskii. (Teoriya i Praktika Metallurgii, 1937, No. 5, pp. 72–76; Chemical Abstracts, 1937, vol. 31, p. 6595). The purpose of this research was to determine the relation between grain size, inclusions and structure, the inclusions being counted on unetched samples. It was found that an increase in the inclusions resulted in an abnormality of the metal and a smaller grain, but there was a definite limit to the size of the inclusions above which it had no effect upon the size of the grain or the structure of the metal.

Morphology of the Inclusions in Siderurgical Products. A. M. Portevin and R. Castro. (Journal of the Iron and Steel Institute, 1935, No. II., pp. 237–280; 1936, No. II., pp. 213P–239P; 1937, No. I., pp. 223P–254P). *Inter alia,* the authors state that the greatest prudence must be exercised when pronouncing judgment on inclusions, as the large number of different inclusions met with in steel makes it difficult to arrive at a true assessment.

Slag Inclusions in Steel. H. Diergarten. (Metal Progress, 1937, vol. 32, pp. 269–271). A description is given of a method of testing developed some ten years ago by the United Ball Bearing Co. (S.K.F.) to determine the size and type of slag inclusions allowable in anti-friction bearings. A minimum of ten bars is taken from each shipment of steel, samples being cut from one or both ends of these bars. To minimise grinding and polishing difficulties, the steel should be hardened, and the surface studied should always correspond with the direction of working. The field of view must be standardised, a magnification of 125 diameters into a field 3 in. in dia. being suitable. The need for standards of comparison for the number and form of slag inclusions became apparent, and eventually a series of sketches was produced, consisting of a number of columns of which each vertical represents a certain type of inclusion and each horizontal row indicates the number and size of the inclusions. The diagram, much reduced in size, is given. In acid open-hearth and acid electric steels the inclusions can generally be divided into two main classes, sulphide and brittle oxides, which are shown in the chart under columns S and B, respectively. In the basic electric steels, however, there is little brittle slag, the oxides existing mainly as larger inclusions in globular, lenticular or flat forms, or in double lines or multiple points as indicated on the diagram. This chart appears to embody a short and uniform method of estimating slag inclusions in practice.

Quantitative Estimation of Non-Metallic Inclusions in Steel. R. Hunter. (Metal Treatment, 1938–1939, vol. 4, Winter Issue, pp. 177–181). After reviewing the methods by which the number of non-metallic inclusions in steel can be assessed by means of the microscope, the author describes a method developed in the laboratory of the Clyde Alloy Steel Co., Ltd. In this method the inclusions are counted and their length is measured, and the statement of results gives the length of inclusions per square inch of steel, the average length of the inclusions and the length and approximate thickness of the largest inclusion.

Report of the Inclusions Count Sub-Committee. (Eighth Report on the Heterogeneity of Steel Ingots, Iron and Steel Institute, 1939, Special Report No. 25, Section IX., pp. 305–322). Examination has been made of the reliability of quantitative methods of estimation of the grading of steel samples with reference to the inclusions content. Normal methods of counting the inclusions, *e.g.*, the Fox and Firth-Brown methods, do not differentiate between large dangerous inclusions and small and less harmful ones, and therefore the count should be supplemented by a general description of the nature of the inclusions present. Tests to ascertain the reproducibility of results were carried out on fifteen steels by different observers, using both the Fox and Firth-Brown methods of counting. Considerable differences in the

counts were obtained by different observers on each sample of steel and the following conclusions were arrived at :

(1) Quantitative attempts to determine the amount and character of the non-metallic inclusions have been and continue to be invaluable to steelmakers as regards control of their own processes and improvement in the cleanness of their steels.

(2) Such quantitative methods, even in the hands of experts, do not produce results sufficiently in agreement for inclusion counts to be incorporated in specifications and adopted for reception purposes.

(3) With further study of technique some satisfactory method may be arrived at, and efforts will be continued to achieve this end.

In an appendix a series of abstracts from both British and foreign technical publications is presented ; these have been selected so as to form a survey of the history of the attempt to count and evaluate inclusions in steel.

Slag Inclusions and Acid Open-Hearth Refining of High-Carbon Steel. H. Styri. (Journal of the Iron and Steel Institute, 1939, No. I., pp. 287P– 296P). An arbitrary scale for slag rating and heat diagrams kept during the melting and refining of acid open-hearth steel at S.K.F. Hofors, Sweden, from the early part of 1927 have been used in statistical analyses to study the possible influence of various operating factors on the resultant slag inclusions in the steel. A description is given of this arbitrary comparative scale introduced by Hofors for the numerical estimation of the amount of slag inclusions of the plastic sulphide type and the brittle oxide slags as follows : A $\frac{1}{2}$-in. disc is hot-sawn from the middle of a billet, approximately 4 in. square, rolled down from selected ingots. A length section is prepared and examined from the centre to the surface under a microscope at a magnification of 100 diameters. Two predominating types of inclusions were considered, namely, the plastic sulphide type, which consists of sulphides or mixtures of sulphides and silicates, and the brittle type, which consists of alumina, aluminates or alumina silicates. The sulphide type corresponds to types A and C in the slag scale issued by Jernkontoret, Stockholm. The brittle slag corresponds to type B. The Hofors scale is numbered from 1 to 4, but covers a narrower range than the Jernkontoret scale, and sections in ball-bearing steel, rated according to Jernkontoret, would give a numerical value approximately 0·5 less than the Hofors scale. The numerical values given for slag rating in steel cannot, of course, be exact, because the composition of the inclusions and the number and dimensions of slag inclusions vary from section to section and from ingot to ingot. A dispersion in numerical values of $\pm$ 0·5 may, therefore, occur. The author states that although the Hofors slag scale was used in the present investigation it has since been replaced by the Jernkontoret scale, since this was issued as standard in 1936.

Classification of Inclusions in Steel. (S.A.E. Journal, 1940, June, pp. 17–19). A method of classifying inclusions in steel has been proposed for use as an S.A.E. recommended practice. The method covers alloy and carbon steels and covers the preparation and selection of samples. The polished specimen is examined in a microscope, each field being projected on a glass screen at 100 diameters. The screen is ruled with parallel lines $\frac{1}{2}$ in. apart (equivalent to 0·005 in. on the specimen), this distance being called a unit. Observations are made of the longest inclusion and of the average length of all inclusions other than the longest and over one unit in length, while a " background rating " includes all inclusions less than one unit in length and is classified according to four photographs, A, B, C and D. Thus, a rating might be 7–2³–B, meaning that the longest inclusion is 7 units, that all other inclusions are 3 in number with an average length of 2 units, and that the background may be represented by the photograph B.

DISCUSSION.

Dr. T. SWINDEN (Member of Council, Stocksbridge) said that, in presenting the paper, Dr. Hatfield had implied some responsibility on his (Dr. Swinden's) part for the Fox inclusion count. He thought highly of the Fox inclusion count but disclaimed any credit for its creation, except perhaps in encouraging Mr. Bolsover to work in that direction. The whole of the work in devising what had been called the Fox inclusion count was Mr. Bolsover's.

Naturally, knowing something of the background of the paper, he had read it through very carefully several times, and he had been relieved, on turning back to the first page, to note that it was only Part I. of the work, because the paper left a good deal to be desired. It was very weak in not drawing logical conclusions and making constructive suggestions from the work that had been done. It purported to be a consideration of three methods of counting, but, with the best will in the world, he thought one was driven to the conclusion that it was a somewhat destructive commentary on the Fox count; in fact, the Jernkontoret method was mentioned only in connection with the quantitative examination of the Jernkontoret and Fox charts, while the Firth-Brown count was mentioned only towards the end of the conclusions in the paper.

There was some quite careful work in the paper, but it seemed necessary to restate clearly what the Fox inclusion count purported to do. Dr. Hatfield invited him to say that it was purely qualitative, but he was sure that Dr. Hatfield did not expect him to do so. The count had limitations which he thought had been clearly understood by all those who had used it, but to stress the method beyond the intention for which it had been originally designed simply created difficulties, such as had arisen, he thought, in the minds of the authors, which they then proceeded to argue about. They showed that by a process of etching and repolishing, which was only very vaguely defined, they were able to reveal fine, evenly dispersed sulphides. Those sulphides must be very fine, because they had not been found before, even with the greatest care in polishing. He would say that, if a method of etching and repolishing was seriously to be considered in looking for inclusions, the conditions should be defined very carefully indeed. To suggest, for example, that one should etch until the surface was " just clouding over " was too vague. The amount of etching required just to cloud over the surface would vary enormously according to the carbon content, for example, and if one was not careful one could get very exaggerated ideas of the inclusions by adopting the method of etching and repolishing suggested in the paper. He did not say that the authors had fallen into that error, but it was an error which could readily be fallen into unless great care was taken in working out the precise technique. But the practical

point remained as to whether the very fine, evenly dispersed inclusions in question were in fact a matter of serious importance.

With regard to the question of the magnification, the figure of 130 diameters was, of course, an arbitrary one.   It was not unusual to adopt an arbitrary figure in such a matter, and there was surely no difficulty in adopting a magnification of 130 or something close to it.   If the figures for magnifications of 82, 132 and 250 in Table II. were examined, it would be seen that the differences were not enormous ; they were not such as to move the steel from one category to another as regards cleanliness, in his opinion, and it was surely no hardship to ask that the magnification should be within those limits.   He did not think that a great point had been made in showing that in using such widely varying magnifications as 27·5 up to 2000 diameters a difference in the count was obtained.

Then there was the further point that the mass of the inclusions, or at least the area as worked out in the paper, did not fall strictly or even approximately into the ratio 1 : 2 : 3 : 4.   In that connection the Fox count did not stand alone, because the Jernkontoret method was equally at fault, but the authors did not attempt to follow their criticism to a logical conclusion.   What would happen if one used 1 : 2·15 : 6·83 : 15·0, as mentioned in the paper, or the three-dimensional figures, was that one would get very high values for the dirtier steel and there would be a considerable spread in the figures that were recorded and probably correspondingly increased discrepancies in the differences between different observers.

Looking at Table V., he gathered that forty samples, twenty electric samples and twenty open-hearth samples, were examined and reported on, on what was called the " old Fox basis " and the " new basis," and, if one adopted an arbitrary figure of 70 as indicating a reasonably clean steel, in only two cases out of the 40 would the category be changed, and even in those cases the differences were not enormous ; 65 became 78, and 63 became 79.   In the case of the much higher figures of the dirtier steel, the fact that 124 became 197 really did not interest him in the slightest ; he would say that 124 was distinctly dirty, and whether it became 197 or 1000 did not make very much difference, in his opinion.   He did not think it was very important, for the purpose for which the Fox count had been devised, to have the value worked out in strictly accurate degree.

In the later part of the paper a good deal of attention was paid to steel No. 8, cast No. $W2255$.   In fact, one might almost imagine that the paper had been written round $W2255$.

Dr. HATFIELD : It was really.

Dr. SWINDEN, continuing, said that the authors had given the identity of some of the steels, and he could therefore state that No. $W2255$ came from Stocksbridge.   The origin of that sample

was interesting and had a bearing on the statement in the paper " It has been said that the slag inclusion count by a well-known method "—that was the Fox method, of course—" would, with a constant amount of non-metallic included matter from oxidation sources, give a consistently low inclusion count, *i.e.*, a high standard of cleanliness, although the sulphur content might be of the order of $0.04-0.05\%$." The circumstances in which the sample $W2255$ had been sent to him would be remembered by Dr. Hatfield; there had been a suggestion that, even with a sulphur content of 0.022%, an inclusion count by the Fox method of the order of 90 was the minimum that could be expected in open-hearth steel. Dr. Hatfield had gone even further and said he confirmed that by calculation from the oxygen and sulphur contents, but that, of course, was quite impossible. One could not calculate an inclusion count from any figures, because it depended on the fact of the inclusion having factors for the different sizes. But there had been a request that a sample should be provided which had a considerably lower count than 90 and still had a high sulphur content, and sample $W2255$ was sent, selected deliberately as being high in sulphur. The Fox count on it, which was not mentioned in the paper, was 41, and it would be seen that the first count by Dr. Hatfield was 25. One could imagine the shock that that gave Dr. Hatfield and his desire to investigate the matter very thoroughly. Dr. Hatfield was satisfied that he had solved his immediate problem by showing that if the sample was etched and repolished the inclusion count was increased considerably.

Turning to Table I., it was perhaps significant that the oxygen content of $W2255$, as determined in Dr. Hatfield's laboratory, was the lowest in the whole series; it was lower than in the first sample, which was absolutely first-class electric steel. Therefore he suggested that it was not unexpected that the oxide inclusions were low and he still thought that the sample represented an excellent quality open-hearth steel. Compared with the twenty samples recorded in Table V., ranging from 82 up to 128 on the old method of counting, it still remained, even on the re-count by Dr. Hatfield, a very clean sample.

The authors claimed to have revealed some intrinsic fallacies and had endeavoured to show the way in which an inclusion-count method could be improved. He was bound to suggest that they had attributed to the Fox method more than had been intended, and he wanted to stress the point that, to evaluate the different effects of different types of inclusions upon physical characteristics, the inclusion count could be regarded only as one factor, and a much more detailed metallurgical examination of the inclusions was obviously necessary.

He would also reiterate that no system of counting could possibly provide all the information necessary in determining the importance and significance of non-metallic inclusions, and he was

afraid that any attempt at that was unsound in conception and quite impossible of fulfilment. Nevertheless, he not only felt but knew that the method that had been used at Stocksbridge had been invaluable in classifying steel according to whether it was very clean, reasonably clean, not so clean, or definitely poor, and if it came into the latter categories it meant that a more detailed examination as to type of inclusion, origin, and so forth had to be made.

In the bibliography at the end of the paper there was a reference to the Report of the Inclusions Count Sub-Committee in the Eighth Report on the Heterogeneity of Steel Ingots,[1] and the first conclusion, drafted by Dr. Hatfield and agreed by the whole of the members, read as follows : " Quantitative attempts to determine the amount and character of the non-metallic inclusions have been and continue to be invaluable to steelmakers as regards control of their own processes and improvement in the cleanness of their steels." That was actually a considered opinion of the Fox method, and he submitted that Dr. Hatfield could not turn that down completely in the light of the further work which had been done. At any rate, personally he had subscribed to that statement at the time and he continued to do so. It would, he thought, have been more useful if the authors, having visualised some methods of improvement, had applied them and indicated the value of the proposed improvements. He thought that some modifications might be necessary, but it was necessary to guard against making the system so elaborate that it could not be worked in a reasonable time as a routine matter. It had not been standardised in its present form without very careful thought being given to that aspect of it. In the paper by Dr. Hunter which was included in the abstracts at the end of the paper now before the Meeting, the proposal to take into account the length of the inclusions was dealt with, and the same subject had been referred to repeatedly by Mr. Dawson. That added to the difficulty, but he thought that in that direction probably the significance of the count could be improved in its relation particularly to transverse properties. He hoped that in the second part of the work greater attention would be paid to the value of the suggested modifications, linked up preferably with a correlation between the count and the properties.

Having spoken at such length already, he would not attempt to discuss such evidence as existed at present with regard to the correlation between cleanness, method of manufacture and mechanical properties, but work was in hand on that subject under the ægis of the Inclusions Sub-Committee, and many people had done individual work upon it. He agreed that it was important to have a full conception of the influence of inclusions on the mechanical properties. As Dr. Hatfield knew, reliance was not being placed on the Fox inclusion count or any other inclusion count on that

[1] *Iron and Steel Institute*, 1939, *Special Report No.* 25, p. 305.

point, but Mr. Whiteley, an expert in metallography, was carrying out an examination of the inclusions in the steels in question, and it was hoped to learn something that was worth while when that work was finished.

Mr. J. H. WHITELEY (Consett, Co. Durham) said that the paper recorded some work that had very much wanted doing ever since inclusion-count methods came into vogue, and for his part he agreed with most of the authors' conclusions. Particularly was that the case with regard to the emphasis laid on the care required in the final stages of specimen preparation. In his time he had polished many thousands of specimens and so thought he could claim some experience in the matter. Like the authors, he had found that a slight etching until the structure was faintly clear followed by a light repolish on the moist cloth was decidedly preferable, especially when many fine inclusions were present. The same procedure seemed advisable also when fine structures were to be examined. Recently he had been investigating austenitic grain growth in medium-carbon steels by the ferrite precipitation method, in which the grain boundaries were revealed by the narrow ferrite borders formed when specimens were air-cooled, and he had observed repeatedly that these ferrite films were liable to remain hidden if they were too fine. A steel containing about 0·45% of carbon would then appear to be completely eutectoid, and in order to discover the ferrite boundaries it was necessary to repolish on the cloth or even to return to the No. 00 paper. It might be that other workers had not experienced this difficulty, for the modes of preparation adopted in the final stages varied considerably in detail; nevertheless he considered that a slight etch and a repolish as advocated by the authors was a safeguard that should always be used in dealing with inclusions.

Dr. Hatfield, in his opening remarks, had stated that the higher the sulphur content of the steel the greater was the number of sulphide inclusions. Broadly speaking that was undoubtedly correct, but he (Mr. Whiteley) was by no means sure that the increase was proportional, since he had reason to believe that some sulphide could exist in solid solution, the amount depending partly on the manganese content of the steel. For instance, he had lately examined two plates of equal thickness in both of which 0·036% of sulphur was present but one had only 0·50% of manganese while the other contained 1·5%, and it seemed to him that there was a definitely greater quantity of visible MnS particles in the latter. At any rate he meant to enquire further in this direction when opportunity occurred in order to ascertain, if he could, how far the sulphur content was to be relied on as a guide to the number of MnS inclusions to be expected. As the authors had pointed out, non-metallic inclusions in steel consisted essentially of sulphide and oxides, and he thought a counting method was

needed which would distinguish between them; in other words, a sulphide count and an oxide count would provide a better evaluation. With present methods a steel low in oxygen and high in sulphur might give the same inclusion count as another high in oxygen and low in sulphur, but it was by no means certain, even when the two were otherwise alike, that their physical properties would be the same. The difficulty was, of course, to devise a convenient counting method which would separately determine sulphides and oxidic inclusions.

The authors stated that the practical object of the investigation was to assess a series of steels from the standpoint of cleanliness, but in reading the lines and between them one gained the impression of a second object which was to have a dig at the Fox method. Yet from a consideration of the results given in Table II. he thought the Fox method did not come out so badly after all. The steels described in Table I. could be divided into three groups in each of which the oxygen contents were approximately equal as shown in Table A. A rough comparison could then be made of the count results in each group.

TABLE A.—*Authors' Steels Grouped by Oxygen Content.*

Group :	1.			2.		3.	
Oxygen Content :	0·0038–0·0042%.			0·0026–0·0028%.		0·0095–0·012%.	
Sample No. :	2.	3.	5.	1.	8.	6.	7.
Sulphur content. %	0·008	0·033	0·041	0·01	0·048	0·022	0·022
Average etched-specimen count . .	18	66	95	12·5	75	82	76·5
Calculated figure .	...	74	92	...	60	...	...

For this purpose he had selected the average of the two counts on the etched specimens at a magnification of 132 diameters, except in the case of steel No. 2, for which a count of 18 had been taken, a figure which appeared to be justified by the results as a whole recorded for magnifications of 82, 132 and 250 in Table II. The rather wide variations between some of the counts at 132 diameters were difficult to understand, as he himself had seldom failed to obtain considerably closer results in check estimations. Under the circumstances, therefore, all that could be done was to arrive at a fair mean in each case after taking note of all the counts given. The procedure was then simple. For example, steel No. 3 contained 4·1 times as much sulphur as steel No. 2, and it should consequently have 4·1 times as many sulphide inclusions on the assumption that the increase was proportional. Thus the figure 74 was obtained as against the average of 66 shown in Table II. He realised, of course, that in making comparisons of this kind a

relatively small constant due to the oxidic inclusions should be deducted from the average figures in the first two groups, but, even so, he considered the correspondence throughout sufficiently close to warrant the conclusion that the Fox method was by no means down and out.

Mr. G. R. BOLSOVER (Sheffield) said he felt somewhat in the position of a prisoner at the bar, charged with having devised and forced upon the industry a system of counting inclusions. To devising it he pleaded guilty, but not guilty to forcing it on the industry. He did not mind at all if not a single laboratory outside Stocksbridge used the system. He himself had used it for a number of years and had found it of the utmost service in deciding whether a particular cast of steel was clean or dirty.

He gathered that there were three counts which he had to answer. The first had to do with the preparation of the section. On that point Dr. Hatfield resurrected the old viscous theory and suggested that in the polishing there was an actual viscous flow which hid some of the inclusions. He did not deny the possibility of that, but he would suggest to the authors that a hardened steel specimen was not the easiest of specimens on which to produce a surface flow in polishing and that with a reasonable polishing technique one did not get that surface flow. The authors then tried to lay that bogey by dipping the sample in acid and allowing it to cloud over, and he agreed with what Dr. Swinden had said with regard to the question of clouding over. He had tried all kinds of acid attack in connection with the inclusion count and had tried even the solution which the authors recommended. He had tried to determine the stage at which the specimen clouded over, and, having more or less successfully decided that, he then left the sample in the acid for another 10 sec. He found that with some of the specimens the extra 10 sec. increased the inclusion count by 50%. If dipping the specimen in the solution until it clouded over got rid of the Beilby layer on the surface, he would like to know from the authors what was removed in the further 10 sec., and, if it was something other than the Beilby layer which was removed in the 10 sec. remaining, was there no possibility of the same thing having been removed in the clouding-over effect ? There, again, he thought all that the authors had done was to confirm work which he remembered being done remarkably well some thirty years ago, on a subject with which he thought Dr. Hatfield would be quite *au fait*, namely, the question of corrosion. It was shown that the first effect of corrosion was on the non-metallic inclusions in the steel, and what Dr. Hatfield was doing now was confusing the counting of inclusions with the counting of corrosion effects.

The next item which he gathered called for some comment was that of magnification. In Table II. figures were given for

magnifications varying from about 20 up to 2000, the last extreme
magnification being 100 times the first one.   Both of those were a
considerable distance away from the standard of 130 diameters,
and he thought it was quite reasonable to suggest that there were
many forms of test where if one varied the standard conditions one
got different results, but, having got those different results, the
authors then proceeded to try again.   He was very relieved to find
that they were improving, and he thought that if they went on
long enough they would achieve success.   He would read out the
results at magnifications of 82, 132 and 250 diameters on the steels
which the authors had tested ; it should be borne in mind that he
had suggested 130 diameters and that to drop to 82 and go up to
250 was a considerable jump.   In spite of that variation from
standard, the results that the authors had obtained with those
three magnifications were as follows, taking the steels in the order
given in Table II. :

Steel No. 1 12, 11, 11	Steel No. 5 82, 71, 61
,, No. 2 20, 18, 20	,, No. 6 64, 57, 50
,, No. 3 35, 36, 41	,, No. 7 56, 52, 52
,, No. 4 48, 42, 40	,, No. 8 58, 46, 50

He could only suggest that there were sufficient data there to
indicate whether any of the steels came into the category of steel
having an inclusion count of 20, 40 or 70.

The alternative to taking the steels in order of merit numerically
was to revert to the system in operation in Britain before the
inclusion count came into being, and that was to say that one
sample was up to standard, that another was dirtier than the
standard, another slightly dirtier, another definitely dirtier, and so
on.   That was no exaggeration ; an effort had been made to deter-
mine the question of non-metallic inclusions before the count
system appeared, and that was the type of description that was
given.   That information might vary very considerably with the
personal factor of the observer.   A quantitative system wiped out
all those difficulties, and a lad of seventeen, who had never used a
microscope before, could give a reasonable result with the method
used at Stocksbridge.

With regard to the question of the standard inclusion fields in
the charts, the authors had taken a great deal of trouble to magnify
the charts, to cut out the areas of inclusions and to weigh them,
and he had no doubt that it had been done in a most methodical
and conscientious way and remarkably well, but why did they ever
attempt to do it ?   It needed only one glance at the Table of
inclusion counts to show that the fields which were labelled 1, 2, 3, 4
were not quantitatively increasing in that order of 1, 2, 3, 4.   No
one had ever intended them to be, and he had never suggested that
they were.   The charts had been built up by taking as grade 1
that field which was thought to show approximately the smallest

group of inclusions that required to be considered in a sample of steel. The other end of the chart was to be the largest group of inclusions which one could find in a piece of steel when it was examined; that became grade 4, and grades 2 and 3 were the two intermediate stages. Having carried out a very careful investigation, the authors suggested that grade 4 relative to grade 1 was as 15 : 1. He did not dispute that; he had not checked it, but he would assume that they were right, and he would say that grade 1 was 1 and grade 4 was 15. He would leave out the half and quarter stages, which really ought to be in, and there would be required in a row along a sheet fifteen micrographs, 1, 2, 3, 4, and so on, up to 15. The chart, however, included not only a progressive increase in the quantity of non-metallic inclusions but four different types of group. He thought the authors had not done themselves justice there. He himself could put down at least a dozen types, but he would say there were half a dozen types of inclusions, and multiplying 15 by 6 gave 90 standard fields which some unfortunate person who was going to examine the specimens would have to carry in his mind, or he would have to refer to the chart every time he had looked at one field out of 160, or whatever the number was, and compare that one field with 90 different standards. That was absolutely impossible, and it was that kind of attempt which had prevented inclusion counts from being used; people had tried to make them too accurate. He granted that the Fox count was not scientifically accurate, but it was a workshop method of test to be applied in a steelworks, and he was prepared to sacrifice something on the side of scientific accuracy for the sake of getting a successful workshop instrument.

On the question of whether a sample was grade 1, 2, 3 or 4, what difference did it make ? Most of the steels examined were made up of fields of grade 0, grade 1 and occasionally grade 2. If most of the fields were grade 3 or 4 it would be a different matter, but, while they were mainly grade 0, grade 1 and occasionally grade 2, one could multiply by 100 instead of by 4 and it would not make any difference.

Mr. SIGURD WESTBERG (Rotherham) said he heartily concurred with Dr. Hatfield in the stress that he laid on the importance of the subject under discussion; it was one of the most fundamental in steelmaking. It was apparently very controversial and he felt that he was on difficult, not to say dangerous, ground. Volumes had been written about inclusions and impurities in steel, but none of them showed any sort of relationship, as far as he knew, to the behaviour and properties of the steel which one wanted to make. He understood from Dr. Swinden, however, that something might be expected on those lines. The investigation of impurities in steel was apparently a matter which did not pay dividends directly, and for that reason it probably ought to be dealt with

collectively.   He himself had been deeply interested in the subject, and, as he had come to Great Britain and his firm had been very well received here, he would like to contribute something to the carrying on of the investigations.   On behalf of his company and himself, therefore, he would contribute £50 for further researches on the subject.

He would like to suggest a somewhat different method of approach.   It might seem rather academic to practical steel-makers, but why should not one start with a pure metal and introduce impurities synthetically as it were, and then study what happened ?   That might appear to be rather difficult, but he had in mind a certain method of carrying it out.   He did not know whether the Members had heard of one method of approach which had nothing to do directly with inclusion counting, *i.e.,* showing the structure of the inclusions as revealed after removing all the metallic matter.   A Norwegian friend of his had approached the subject by removing all the metallic matter in a rather in-genious way (the method was not a practical one, as it took too long), at a very low temperature, leaving what might be called the remaining structure of the non-metallic matter intact.   It was a very light structure that could be simply blown off the hand. The interesting point was that it retained the shape of the original matter.   Some of the steels which had been actually tested in practice would show a great number of inclusions or a rather heavy structure, or a non-metallic skeleton, and yet show up to the best advantage.   In the way he had personally suggested he thought it might be possible to obtain a correlation between the inclusions and the properties and behaviour of the steels.

CORRESPONDENCE.

Dr. D. BINNIE (Irlam, near Manchester) wrote that Dr. Hatfield and Mr. Giles had carried out painstaking work on the standardisa-tion of a method of inclusion counting.

They had undoubtedly shown that the gradings could be put on to a rigid mathematical basis, and thus had widened the sphere of application of inclusion counting, making it more adaptable to varying conditions.   Thus, inclusions too small to be evaluated by existing standard-magnification methods could now be given a grade number.

Since Dr. Hatfield's paper had now standardised a method of counting inclusions, the next step was to standardise, with similar precision, a method of polishing.   He (the writer) was fully aware that this question had been stressed by all interested laboratories, but nevertheless the subject had not been developed to such an extent that the personal factor could be at least minimised.

Could some manufacturer not be approached to produce and

supply an approved polishing powder of regular abrasive properties available to all? In his experience, which he was sure would be shared by many, the properties of the polishing powder were of more importance than the materials used in the earlier stages leading up to the final polishing. This would go a long way to reduce the apparent inconsistencies found between different investigators.

The whole matter of the grading of steel on an inclusion basis had been given great publicity recently, but only on the counting of inclusions, and it was hoped that an effort would be made to publish the metallurgical importance of these inclusions, otherwise false impressions were apt to be built up in the minds of consumers regarding the suitability of steels for their purposes.

Mr. E. WOOD (Coventry) wrote that before the fairly widespread use of methods of inclusion evaluation based on charts it had been customary for the user (where inclusions were considered at all) to arrive in conjunction with the steelmaker at some mutually agreed " standards " of acceptance. Approval was based on a more or less carefully chosen sample submitted by the maker to the user. The cast was then reported as good, fair, acceptable, moderate, borderline, poor, rejected, or by an even greater number of similar imponderables.

Where the user's laboratory had a modicum of skill and experience at its disposal this worked reasonably well, though the " borderline " standard was often wrangled over. It had always seemed to the writer that any method of evaluation based on charts was merely an extension of this arbitrary arrangement, and any criticism of the degree to which they were quantitative which overlooked this was tilting at windmills.

But if this fundamental was realised such methods were a real improvement and became of practical value and importance. Especially was this so when expansion of output was necessary and subcontracting and " shadow " works were used, where less specialised experience might be available. Methods based on charts had yielded, and were yielding, valuable results. As research or absolute methods they failed at the outset. Here analysis, or some such method as that of Smialowski or Dr. Hatfield's paper method must be used, and many samples from different ingots taken to enable a final judgment to be made concerning the average or statistical dispersal of non-metallics in a cast.

For successful working of a chart method the following factors were necessary :

(1) Proper selection of the sample.
(2) The necessary skill and experience in the consumer's laboratory.
(3) Proper preparation of the sample (this was really a subdivision of 2).

(4) A set of charts as wide in range and as nearly fool-proof as possible.

Item (1) seemed scarcely to need stressing, but the writer had had samples of all shapes and sizes submitted, from wire to 6-in. bar. It might be worth while to stipulate the degree of reduction from ingot to final sample rather than to stipulate a rigid size for the latter—thus a large ingot might be represented by, say, a forged 2-in. bar, and smaller ingots by correspondingly smaller bars. This postulated, of course, a set of charts for each sample size. If this were considered an unnecessary complication a set of charts could be devised which, by assessing relative values of small and large inclusions, enabled one standard size of sample to be used.

Item (2) was most important. One assumed, when speaking of inclusions, that actual masses of sulphide, silicate or oxide were meant, and not corrosion pits, dragged cavities, smeared or flowed surface layers, or what not. It was perhaps worth mentioning that a camel-hair brush was a most important adjunct to the inclusion-counting microscopist.

Concerning item (3), it had been the writer's method to use similar principles in polishing to those set out in the paper, *viz.*, to quench the specimen and, after suitable rubbing down, to polish as rapidly as possible on a wet pad with a minimum of abrasives. Chromium sesquioxide was preferred to alumina, because of the occasional polish attack experienced with the latter. In any case of doubt whether a particular mark was an inclusion or whether its shape and size were apparent or real, a magnification high enough to resolve the structure or texture of the suspected inclusion was used. If doubt still existed (which should be rare), repolishing was carried out after light rubbing on emery. The effect of new and old polishing media noted in the paper had been observed by the writer.

With regard to item (4), standard charts, the Fox method had been chiefly used in the writer's laboratory, and he had pointed out on several occasions that the charts for this were not inclusive enough. As Dr. Hatfield pointed out, numerous fine inclusions were completely missed if they were smaller than those on No. 1 standard, no matter how numerous they might be, and large inclusions could receive far less than their true value compared with the general scattering of smaller particles. To overcome this the following method was adopted : Instead of counting across two lines at right angles to the longitudinal axis of the specimen, the latter was divided (either by eye, or by the usual scales on the mechanical stage of the microscope) into sixty squares, and the *worst* field in each square was taken for the final evaluation. A large inclusion thus received more nearly its true value, for if it persisted through, say, six fields it was counted six times. Fine

inclusions smaller than grade No. 1 on the chart were counted as half, and their total was added to the final count. It was probable that something between the Fox chart and the Jernkonteret chart was needed.

Reference was made in acceptance or rejection to the type of inclusion, as had been recommended by many authorities, and rejection was never made without considering the type of service to be expected from the steel. With these emendations it had been found that the general standard of cleanness of steel for aero-engines could be kept at a satisfactory level, and this in itself was an achievement for a method which was still fundamentally arbitrary.

Diagrammatic charts seemed to be preferable to actual micrographs, as, in the writer's opinion, no such thing as a " typical " field existed on an unetched or lightly-etched microsection. Whether steel were classed as clean or dirty, wide variations could exist between given fields. The Society of Automotive Engineers' method attempted to solve this difficulty ; " particular " or " background " inclusions were evaluated and numerically designated.

To etch or not to etch ? Of the value of etching in particular cases there was no doubt. One had a lively recollection of a dispute with a well-known maker of ball races whose metallurgist polished the contested sample in the writer's laboratory on an almost dry pad with rouge and triumphantly demonstrated that very few inclusions were present. A light etching revealed angular silicates, elongated sulphides, strings of aluminium oxide and one or two crystals of nitride.

The criticism in the paper of the lack of agreement between grades 1, 2, 3, and 4 in the Fox charts and the numerical ratio of the values or projected paper weights of the inclusions represented did not seem to be relevant. There was no mathematical reason why two should always mean twice one nor that a count of 100 should necessarily mean steel twice as dirty as a count of 50. What *was* relevant was that the user should determine for himself what a count number meant in terms of his own requirements ; 100 might be " clean " for bicycles, but " dirty " for aero-engines, connecting rods or high-speed turbine parts.

The question of the precise effect of inclusions on the properties of steel had still to be answered. Portevin had dealt with it in his usual lucidly critical manner. The time had not yet arrived when the terms " clean " and " dirty " were absolute. Not only must the use and environment of a part be considered, but the type of steel, fabrication and heat treatment must all be considered when making a judgment of the degree of cleanness required. In a case-hardened part, for example, inclusions in the end section relative to the cased surface might be less important than when they were longitudinal. On high-grade spring wire, where the wire itself might be used as a specimen, it had always seemed to

the writer that a much more critical examination and judgment should be made than on a properly prepared sample of large diameter.   The cleanness of parts broken in service and of parts that had given successful long life should also be used in arriving at standards of acceptance.   It was at any rate possible that the presence of inclusions was more important as an indication of the steelmaking conditions than their direct effect on mechanical properties, *i.e.*, more trouble had been experienced from roaks, laps, seams, large inclusions, &c., in steel which was generally " dirty " than in that which was generally " clean," though parts made from the former when they did not contain such macro-defects might give quite satisfactory service.

In conclusion, the writer hoped that the work would generate renewed interest in inclusions and their counting, and result in a concerted attack on the problem of a more acceptable " quantitative " method of evaluation suitable for routine use.   Certainly the authors of the present study were to be congratulated on their inaugural and highly original paper work.

Dr. S. A. MAIN (Sheffield) wrote that the authors observed on p. 250 P that " if the method is based upon intrinsic fallacies and on non-quantitative data, reasonable agreement on the figures arrived at is none the less of little value in assessing the relative cleanliness."   With that he was in wholehearted agreement, and considered that it applied to any of the micrographic methods now being exploited.

The methods employing charts as a basis of comparison had been introduced admittedly, as the discussion had shown, as an imperfect means but the only kind available on a practical basis at present.   Should it not always be in view that such methods must be discarded as soon as more rational methods could be devised ?   The fact was that attention was being concentrated rather on the development of and attempts to perfect those irrational methods, and the devising of more rational methods to that extent was put in the background.

Visual judgment of cleanliness from a microsection was, without exercising special care and thought, liable to misconception as to the true facts.   If the particles were all of uniform size, one would still see in the microsection particles of graded size down to the limit of visibility.   Although in practice they were not actually of uniform size, it could be shown mathematically that the grading seen in the microsection still gave a wrong idea of the actual distribution of sizes of the particles.

Examining a number of counts, made in the laboratory of his firm, of inclusions in their various categories of sizes, the writer found that, when plotted in the manner of the chart shown in Fig. A, they could usually be represented by a straight line.   It was clear that the actual distribution could not stop short at

the left-hand end of the line, which was determined only by the limit of visibility. In other words, a reasonable extrapolation of the line in this direction was permissible. There were, in fact,
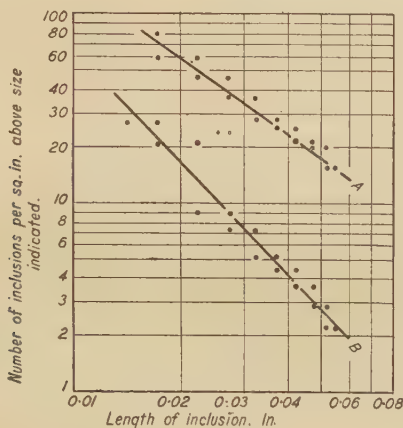
FIG. A.

still smaller inclusions in large numbers which could conceivably add appreciably to the bulk actually observed, and ought therefore to be taken into account in assessing the cleanliness of the steel.

The real purpose of the chart was, however, to demonstrate the hopelessly non-quantitative character of the present highly empirical methods. Of the two examples shown, the one represented by the upper line A, which was actually a basic open-hearth nickel-chromium steel, contained from four to seven times as many inclusions above any one size as seen in the microsection as that represented by the lower line B, which was an acid steel of the same composition; yet the Fox values averaged 143 and 123, respectively, a ratio of only 1·16. In another case, with the numbers of inclusions above any one size in the ratio of between 2 and 4, the Fox assessment made no discrimination between them. Reasonable agreement between the two methods was, in fact, rare.

It would seem that nothing short of actual separation of the inclusions by chemical or other means was ever likely to be satisfactory. The difficulties were appreciated, but the writer thought that efforts would be better applied in that direction than in trying to perfect the present basically unsound methods.

Mr. H. W. PINDER (Sheffield) wrote that it was suggested in this paper that, regarding the preparation of specimens, as long as the scratches were normal to the direction of the inclusions it was not essential that they should all be removed. This in itself was quite correct, but in order to minimise the flow of metal which

would appear to take place round the inclusions so that part of them was obscured, it was suggested that final polishing should be in a direction parallel to the inclusions. Although it was difficult to control preparation to conform to these conditions, it could be met in a large measure by using the outside portion of a fairly large-diameter wheel, say, of approximately 8 in. diameter.

Regarding the results given in Table II., the majority were such as to show that etching did not increase the count to any appreciable extent.

The section from cast $W2255$, first column, which counted 21 as received, counted 50 after etching, but also 60 after a repolish only. Thus it appeared that a repolish would on many occasions bring the count into line as well as etching. If the majority of the inclusions were in such a plane as just to break the surface, then a larger proportion of their surfaces would be affected by the flow of the metal during polishing and a low count would result. If the majority of the inclusions broke the surface so that the greater proportion of their surface area was exposed, then the count would not be in such great error, because the percentage area affected by flow would be much less.

Taking the results in Table II. as a whole, the usefulness of the Fox count would appear to have been confirmed rather than refuted.

One outstanding result under steel 6, in the 27·5-diameter column, was that a considerable reduction in the count of this steel resulted after etching. Even this refinement would appear not to be free from anomalies. Finally, the fact that counts had been given to decimal places must be strongly deprecated, as a quite false impression of accuracy was conveyed to those lacking first-hand experience.

Mr. D. A. OLIVER (Sheffield) wrote that this paper should prove a valuable antidote to those metallurgists who attached undue importance to an inclusion-count number. In the essential nature of the problem no single number could ever be a truly quantitative evaluation of the non-metallic inclusions in a sample of steel, for the simple reason that the inclusions present differed in type among themselves and were not interrelated by any known mathematical function which would determine how each type would contribute to the final number. From this point of view, to seek a more accurate counting method might be misguided effort, and thus one was forced back, with all its limitations, to a some-what over-simplified empirical method such as the Fox inclusion count, which, nevertheless, had proved to be of considerable value in the control of quality steels. In the writer's opinion, changes in technique in polishing and counting should be assessed more from the standpoint of whether they affected the order in which steels were graded rather than from the mere correctness of the number

attached to a particular steel, and with this the authors were likely to agree.

Assuming " cleanness " to be assessed in the usual way by the Fox index, it was clear that a more fundamental approach to the matter was needed, which should develop from a comprehensive study of the effect of inclusions on the mechanical properties of steel components and test-pieces. It was widely admitted that a few large inclusions were more harmful than more numerous small inclusions, and it was common practice to reject supplies and components with inclusions larger than a certain size, irrespective of the general degree of cleanness of the steel. On the other hand, it was not unknown that steels having an appreciably higher inclusion count than other steels which were numerically classified with a lower count (and were unarguably cleaner) did, in fact, on mechanical test give better test figures than the so-called cleaner steel. Contradictions of this kind indicated that transverse tensile and bend tests were very sensitive to non-metallic matter in steel, not from the inclusion-count angle but from the aspect of the real harmfulness of such inclusions. Whatever might be the limitations of these mechanical tests, there did seem to be increasing evidence of their reliability in specific instances.

In the writer's laboratory, work was in progress in which slags of known composition were deliberately introduced into blocks of clean steel, and the resulting structures were being studied after various forging and heat-treatment procedures. This might give useful information from a different angle, and was not dissimilar from some of the investigations which had already been mentioned in the discussion by Mr. Westberg. Other work was concerned with the effect of inclusions outcropping on the surface on the torsional fatigue strength of certain steels, and it was hoped that explorations in several directions simultaneously would enable more definite ideas to be formed as to how the effect of inclusions should rightly be assessed.

It was the writer's conviction that in course of time the focus of interest would move from a numerical assessment of the numbers of inclusions present to a limited number of mechanical tests which were known to be sensitive to the presence of residual inclusions.

Mr. H. S. BAVISTER [1] (Luton, Beds.) wrote that any work relating to the cleanliness of steel was vitally important to any steel consumer, whose progress in developing mechanisms of ever increasing performance necessitated that his every pound weight of steel should be capable of withstanding the transmission of ever increasing amounts of energy. The correlation of fatigue performance with cleanliness seemed to be a real but vital gap in our present knowledge. (The effect of cleanliness upon high-speed machining-tool life was quite another aspect which could occasionally loom large

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[1] Vauxhall Motors, Ltd.

in production costs.)   The Fox method had, therefore, satisfied to a degree the large need of the consumer for a method of a sufficiently simple and quick character as to be applicable to the routine acceptance of steel supplies.   While, therefore, one could thoroughly admire the large amount of careful and accurate work described in this paper, its conclusions were very depressing !   One rather wondered whether the authors had not been attempting to investigate this particular method in relation to terms of absolute quantitative accuracy which could probably never have been seriously urged for it.   The method was obviously approximate, dependent to a considerable degree upon the human element, and based upon arbitrarily chosen conditions and standards ; it was not surprising, therefore, that it did not withstand searching mathematical and geometrical analysis, but that did not, in his view, preclude its having usable relative accuracy.   While it might only compare instead of measuring, its results might still be of real value to the consumer—particularly as there seemed to be no sign of any equally practicable or more accurate procedure.

It was very interesting to read the results of the determination of the total inclusion area of the four standard Fox fields ; he had always had the feeling that these should have been rated as $1 : 4 : 9 : 16$.   This feeling had merely arisen from a guess as to the relative effect of the various sizes of inclusions upon the steel performance ; it was not an entirely unreasonable suggestion that " plastic " type inclusions of more or less globular shape and of uniformly small dispersion might not be harmful ; they could possibly even be of some small value from the point of view of resistance to crack initiation and propagation, under fatigue-stressing conditions.   Certainly his limited experiences would suggest that if we could have a guarantee of complete freedom of our steels from the relatively massive stringer agglomerates that did sometimes occur, particularly in fine-grained steels, our worries would become much smaller.

He did feel, therefore, that, despite the obvious validity of the experimental work in this paper, the existing method, with its shortcomings, should continue to be applied as much as possible ; large experience with the method could be expected to indicate more clearly the best directions for refinement or modification, and, of course, the method did permit the consumer to take a little intelligent interest in a very vital condition of his materials.

With regard to polishing technique, the writer always polished at $45°$ to the direction of the " grain " ; scratches were thus never confused with any inclusions, and he was able to achieve a $90°$ change of direction of polishing with consecutive papers, &c.   He finally polished on Selvyt cloth with magnesium oxide, but he added to the distilled water $0·1\%$ of potassium dichromate ; this did seem advantageous in preventing incipient corrosion effects from giving exaggerated appearances to inclusions, pits, &c.

He would mention that the degree of reduction from the ingot did have an effect upon the Fox number, and that it would be useful if this general ratio of variation with size of bar could be established; very many of the sections purchased by the consumer did not permit the preparing of the standard $1\frac{3}{8}$-in. dia. specimen.

The writer could assure the authors that the implied Part II. of this paper—with its anticipation of a better evaluating procedure —would be eagerly awaited.

AUTHORS' REPLY.

Dr. W. H. HATFIELD, F.R.S., in reply, said he did not think he need reply at length to the discussion, as his object had been fully achieved.

Dr. Swinden had said that the quantitative evaluation was unsound in conception and impossible of fulfilment, but why, if that was the case, were steelmakers subjected to the quantitative inclusion count as a means of commercially receiving steel ?

Mr. Bolsover was quite right ; he, as an honest investigator, had devised the method and used it in his works, and other people had taken it up. He did not say how much encouragement they had had from Mr. Bolsover, but other people had taken it up and it had been imposed for commercial purposes. He thought it would be generally agreed that it was too early to impose a quantitative method for evaluating the inclusions in steel.

In Table II. would be found the crux of the whole matter. Taking the last steel in that Table, No. $W2255$, it would be seen that when first received that steel had an inclusion count of 25 at a magnification of 132 diameters. It was indeed the cleanest of the Siemens steels. The corresponding figures for the next three steels, taking them in order from the bottom of the Table, were 77, 79 and 100. Taking the magnification of 1200 diameters and the etched value, *i.e.*, the value after the light etching to remove the so-called amorphous Beilby film, it would be found that No. $W2255$ had an inclusion count of 55, which was the highest of the Siemens steels ; in other words, it was the dirtiest of them all. If the Members referred to the table of analyses they would find, if they added together the sulphur content and the oxygen content of that steel, that it was the dirtiest one of the series. If they added the manganese sulphide and an extension of oxides from the oxygen, they would find that it was in fact the dirtiest steel of the series, and the methods which he and his colleagues had adopted in their investigation showed it to be so. He thought that was all that was required to complete a very interesting investigation ; it was the end of the story as far as it went. The work had confirmed that the method was a non-quantitative, or qualitative, one. He hoped, with the assistance of Mr. Giles and his other colleagues, to contribute very materially to

the subject, but he would always bear in mind that sulphur, producing sulphide, was one of the greatest enemies of those who required a homogeneous clean steel free from non-metallic inclusions.

Dr. Hatfield was grateful to those gentlemen who had taken the trouble to submit contributions to the discussion in writing. These all emphasised the importance of the subject and how essential it was to obtain a reliable method of estimation of the content of non-metallic inclusions in steel. He was in general in agreement with most of the remarks made in these contributions, although a few items of criticism had been made. Mr. Wood, for example, had stated that an exact numerical ratio of the values of the counts of the different fields was not relevant. He had tried to show in his paper that the non-proportionality of the counts for the various fields was an important source of error in certain cases in assessing the total count. It would be appreciated that, since the counts for the various fields were added, the numbers used must be additive and therefore should be proportional to the inclusion content of the field. To illustrate further the importance of this, consider the simple case of two steels in which four fields were examined, one having counts of 0, 0, 0 and 4 and the other of 1, 1, 1 and 1. On the Fox basis both these steels would have the same inclusion count, but if the field No. 4 contained actually 16 times more inclusions than No. 1, the first steel on the whole contained four times more non-metallic matter than the second steel.

He agreed with Mr. Wood, Mr. Oliver and Mr. Bavister that a knowledge of the precise effect of inclusions on the properties of steels was desirable, but this was outside the scope of the paper. Apart from the effect on the properties of the nature and size of the inclusions, an important factor was, of course, the location of the inclusions in relation to the service stresses. In effect, the total inclusion count was not so important as regarded the mechanical properties as the nature and size of the individual inclusions.

Dr. Main's contribution emphasised the non-quantitative character of the present methods.

In conclusion, Mr. Bolsover had said that the Fox count was not scientifically accurate, but it was a workshop method of test to be applied in a steelworks. Rough workshop tests were not used as acceptance tests, but the trouble was that consumers were prone to adopt this rough workshop test as a means of acceptance or rejection. Until a method could be obtained which would overcome the deficiencies of the Fox count, and bring it down to a more scientific basis, it would be unwise to use it for any purpose other than that for which it was originally intended, and even in such cases it was liable to give erroneous information.

METHOD OF SCLERO-GRATING EMPLOYED FOR THE STUDY OF GRAIN BOUND- ARIES AND OF NITRIDED CASES; GRAIN STRUCTURES REVEALED BY CUTTING.

By BO O. W. L. LJUNGGREN (METALLOGRAFISKA INSTITUTET, STOCKHOLM).

This paper was discussed at the Annual General Meeting held in London on May 2 and 3, 1940; in the author's absence it was presented by Dr. C. H. Desch, F.R.S. It will be found, together with the discussion to which it gave rise, in the *Journal of the Iron and Steel Institute*, 1940, No. I., p. 341 P. The author, owing to his absence on active service, was not able subsequently to deal with the comments made, and the following reply was prepared by Professor C. Benedicks, of Metallografiska Institutet, Stockholm.

REPLY TO THE DISCUSSION.

Professor C. BENEDICKS wrote that it was much appreciated that Dr. O'Neill had pointed out that the quest had important practical relationships, *viz.*, regarding the inherent grain-size behaviour of steel. When Dr. O'Neill expressed the opinion that " this laborious method of ' mechanical etching ' had unfortunately given negative results, except . . .," the adverb " unfortunately " quite well expressed the author's primary sentiments. Considering several questions now dealt with, however, the *negative* result of the majority of the experiments seemed actually to be a blessing in disguise. As a matter of fact, Dr. O'Neill said that, even if boundary hardening could be conclusively demonstrated, it would be necessary to eliminate the possibility of (1) amorphous cement, (2) lattice-transition effects and (3) preferential hardening at the boundaries due to polishing. Concerning (1), the point was actually that the hypothetical amorphous cement of Beilby, supposed to be extremely hard, would obviously occur likewise in ordinary metals not annealed in nitrogen. Hence, it was of considerable interest to know that, having regard to the sensitivity of the method used so far, not the slightest sign of the presence of any hard amorphous cement could be traced. Exactly the same applied for items (2) and (3). These three factors, consequently, could not be held responsible for the boundary hardening observed after annealing in nitrogen—a fortunate fact.

Dr. O'Neill's criticism of Fig. 65 was by no means unjust. Reproducing it for another purpose, Professor Benedicks had actu- ally found it appropriate to preserve only the line *aa*—now conceded as correct. The other lines had in fact been drawn after using

not only the original unreduced micrograph, but also the actual specimen. Thus, they might be quite correct in themselves. The fact that they were not as reliable as could be desired was the reason why, in Fig. 64, the same micrograph had been reproduced without any subjective interpretation.

It was to be regretted that Dr. O'Neill's most interesting result of 1928 had not been noticed by the author; his Fig. 11 [1] illustrated beautifully the phenomenon of greater hardness in the boundary now sought for. This greater hardness in the boundary of two strained ferrite grains might be explained in the following way : As it was well known that cold-working produced a smaller hardness increase in a pure metal than in an alloy, it might be natural to assume the above excess hardness to be primarily due to a *chemical concentration* process in the grain boundaries, giving a hardening enhanced by the subsequent straining. Thus Dr. O'Neill might claim priority in having observed a greater hardness in the boundary. Of course, the deformations taking place near a strained boundary were of a very complicated character.

Finally Dr. O'Neill's remark that the sclero-grating method clearly revealed the presence of cold-worked metal—as had been proved in some of his (Dr. O'Neill's) earlier work—whereas Tammann had repeatedly stated that scratch-testing did not react in that way, was interesting. It might be justifiable to say that, using (like Tammann) a sharp pointed tool, the effect of cold-working would be very hard to perceive. As pointed out in the above discussion, p. 394 P, the " sensitivity " increased with increasing angle α; in the case of a hemispherical point (O'Neill) α approached the maximum of 90°; hence, the sensitivity for small hardness differences must then be greater. The highest sensitivity, however, was obtained when using not single scratches but a *grating*, especially when a secondary point came into action.

The author entirely agreed with Dr. Chalmers when he pointed out that the character of a boundary necessarily depended on the angle (A) between the crystallographic axes of the two adjacent grains. Strictly, it likewise depended on the orientating angle (B) of the boundary in a given point. Thus, if P designated a property of the boundary, such as capillary enrichment, then $P = f (A, B)$. For $A = 0$, P vanished for any value of B, *i.e.*, no boundary existed ; for definite optimum values of A and B, P would be a maximum. Hence, as Dr. Chalmers rightly pointed out, the capillary enrichment might differ widely along the boundary of a given grain.

The experiments made by Dr. Chalmers with Mr. Hoare,[2] in which the levels of a polished metal surface were determined by interference fringes, were interesting. In the present work, however, it had been amply verified—though but briefly mentioned—

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[1] *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1928, vol. 17, Plate XVI.

[2] *Journal of the Iron and Steel Institute*, 1935, No. II., p. 135.

that a small elevation or depression of a surface exerted in itself no appreciable influence on the width of a scratch, the velocity of ruling being expressedly chosen so low as to eliminate any such influence.

As Dr. Chalmers had so justly put it, " this was essentially a new application of a new method," and it was quite natural that some of the observations, being only just within the experimental limits, could not claim to be quite convincing. Thus, supposing a portion of a boundary to appear convincingly harder than the adjacent grains, without any precipitated hard phase being visible, it was almost impossible to prove that such a phase did not occur and *end just below* the surface !

It seemed quite logical to assume, with Dr. Chalmers, that the sclero-grating method might prove useful for the study of electro-deposits.

Dr. Desch's remark, regarding the revealing of the structure of an alloy by a fine machining tool, that in one of the plates in Sir John Dewrance's Presidential Address in 1927 no chemical etching had been used, was very interesting (in the text, unfortunately, no indication of this was to be found). In a similar way machining had been used to advantage for revealing the presence of non-metallic inclusions. Anyhow, the fact that the grain structure was well revealed when using a knife-edge seemed to be new for the present work—though earlier observations might well have been made.

It was especially interesting to learn from the remarks of Dr. O'Neill and Dr. Desch that earlier observations of the cellular structure of nearly pure metals existed than those mentioned in the footnote on p. 394 P of the paper. The work of Professor Mason (1935) was particularly noteworthy. All this considerably strengthened the theoretical explanation attempted in the paper—severely criticised in the author's country. The revealing of this structure in lead by cutting, without any etching, seemed to be quite new.

Thus, the discussion had brought forth many valuable points of view—for which the author and Professor Benedicks were highly indebted.

THE OXYGEN/HYDROGEN/MOLTEN-IRON SYSTEM.

By HENRY LEPP, Docteur-Ingénieur (Dives-sur-Mer, France).

This paper was presented at the Annual General Meeting held in London on May 2 and 3, 1940. It will be found, together with the correspondence to which it gave rise, in the *Journal of the Iron and Steel Institute*, 1940, No. I., p. 329P. The author's reply was not received in time for inclusion with the paper itself, and is printed below.

REPLY TO THE CORRESPONDENCE.

Dr. LEPP, in reply to Dr. McCance, wrote that he wanted first to emphasise that on the basis of his paper it was rather difficult to admit his intention to re-discover the laws of thermodynamics and to show that they could be applied to chemical equilibria and in particular to the system oxygen/hydrogen/molten-iron. Applying these well-founded classical laws, he based his calculations on known researches, in particular, on the experimental results of Sieverts, and of Chipman and Samarin, to which he tried to give another interpretation, by a form of " synthesis." The purpose of the present short paper was obvious, namely, to draw attention to the fact that the mechanism of the reaction of H_2O with molten iron was, in his opinion, not represented with sufficient exactness in the classical form :

$$Fe + H_2O \rightleftharpoons FeO + H_2 \text{ and } K = \frac{(H_2)}{(H_2O)} = \frac{(p_{H_2})}{(p_{H_2O})},$$
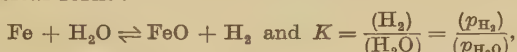
as the absorption of hydrogen and oxide by the molten iron was not taken into consideration.

No one would dispute the results obtained by Sieverts, who had shown that hydrogen was absorbed by iron in the atomic state. In the present case it was of less importance whether this absorbed hydrogen was present in solution or as a hydride (FeH). In fact, at the moment it was very difficult to prove either possibility. The author, personally, was inclined to assume the hydrogen to be present as the hydride FeH (with a negative heat of formation), because the absorption in this case was an endothermic process, and, further, this would be in good agreement with our present knowledge of the formation of hydrides as derived from the periodic system.[1]

Using in his discussion and calculations the reaction of the thermal dissociation of H_2O (vapour) as the intermediate stage, the author based his reasoning on Hess' classical law, which, so far

[1] Lepp, *Metal Industry*, 1938, vol. 53, July 15, pp. 59–63.

as he knew, was still considered valid. Nowhere in the paper was the question raised whether this water vapour was or should be dissolved in molten iron; but it was interesting and he would be glad to learn Dr. McCance's views on the solubility of water vapour itself in molten iron at 1525–1800° C. (not of the reaction products, oxide and atomic hydrogen).

With regard to Mr. Phragmén's remarks, the author wished to thank him for the care he had taken in interpreting the equations developed in the paper, and, in particular, for his warning against the confusion of molar and weight percentages when referring to the FeO concentration. This applied equally to (FeH) occurring in the author's equations. In all his equations FeH represented the percentage of hydrogen absorbed by the iron. In the author's opinion, as pointed out above, this absorbed hydrogen was present in the form of a hydride, and that was why he employed the formula FeH for it in his equations.

With regard to the equation :

$$\text{Log} \frac{(\% \text{ H})^2}{\{\text{H}_2\}} = -\frac{3180}{T} - 3 \cdot 46 \quad . \quad . \quad . \quad . \quad (a)$$

proposed by Mr. Phragmén, which from a thermodynamical point of view was identical with the author's, he would also like to give a warning against confusion with the thermal dissociation of hydrogen (Langmuir's equation). In this latter case it was thus necessary to make clear that the gas was in contact with iron.

The author fully agreed with Mr. Phragmén that equation (a) together with the following equation :

$$\text{Log} \frac{\{\text{H}_2\text{O}\}}{\{\text{H}_2\}(\% \text{ FeO})} = \frac{10200}{T} - 5 \cdot 50 \quad . \quad . \quad . \quad . \quad (b)$$

were adequate for the determination of the amount of hydrogen and oxygen in molten iron. There was also no doubt that the mathematical manipulations proposed by Mr. Phragmén led to the general equation :

$$\text{Log} \frac{\{\text{H}_2\text{O}\}^2}{(\% \text{ FeO})^2 (\% \text{ H}_2)^2 \{\text{H}_2\}} = \frac{23580}{T} - 7 \cdot 54,$$

which, too, was identical with that suggested by the author. In his paper he had only tried to give chemical and thermodynamical fundamentals and reasons by combining equations (a) and (b). In his opinion this general equation represented the process of inter-action between H_2O and molten iron in a more complete form, and, in particular, it also took into consideration the gaseous phase of molecular hydrogen above the metal, which was determined by the classical equation :

$$\frac{(\text{H}_2\text{O})}{(\text{H}_2)} = \frac{p_{\text{H}_2\text{O}}}{p_{\text{H}_2}}.$$

He did not wish to debate, in this connection, the implications of the words " best " or " more convenient."

With regard to the question raised by Mr. Phragmén on the interpretation of the curves represented in Fig. 5, it would seem useful to refer first to the paper. As pointed out, these curves had been obtained by interpolation and they were applicable only up to the limit of solubility of FeO in molten iron. For this solubility Mr. Phragmén referred to the equation of Chipman and Samarin; there were many other equations, e.g., those cited by Schenck [1]; the investigations of Körber and Oelsen had already been mentioned in the paper. The only thing to do was to select and apply the results obtained in the general equation proposed by the author.

If the limits of solubility of FeO in iron were exceeded the excess of FeO passed into the slag, which process was governed by the following equation :

$$L = \frac{\text{FeO \% in the metal}}{\text{FeO \% in the slag}} \quad \cdots \quad \cdots \quad (c)$$

The author's curves, obtained by interpolation, became straighter and more parallel to the x-axis from about 20% of FeO onwards. Thus, up to 20%, FeO was still practically effective in eliminating the hydrogen, in accordance with the law of mass action. In fact, however, the solubility of FeO in liquid iron was far from these proportions. Therefore, one must seek its action in eliminating the excess of hydrogen not in the molten iron itself, but in the intermediary of a slag according to equation (c), making use of the law of mass action.

In conclusion the author would like to thank Dr. McCance and Mr. Phragmén for their comments on his paper. From their contributions he believed he could conclude that they admitted, in principle, the co-existence of oxide and atomic hydrogen in molten iron, as he had set forth in his paper.

Consequently the classical equation :

$$K = \frac{(\text{H}_2)}{(\text{H}_2\text{O})} = \frac{p_{\text{H}_2}}{p_{\text{H}_2\text{O}}}$$

as well as that given by Chipman and Samarin :

$$K = \frac{(\text{H}_2\text{O})}{(\% \text{ FeO})(\text{H}_2)}$$

required a correction and to be made more exact.

[1] Schenck, "Physikalische Chemie der Eisenhüttenprozesse," vol. 1, p. 132. Berlin, 1932 : Julius Springer.

OBITUARY.

Sir ROBERT ABBOTT HADFIELD, Bart., D.Sc., F.R.S., who died in London on September 30, 1940, in his eighty-second year, was probably better known to the general public than any other metallurgist; certainly, the inventions and developments in metallurgy that are associated with his name merited for him the greatest recognition, and, in fact, such recognition was made to him during his lifetime.

Sir Robert was born in Sheffield in 1859; he received his general education at the Collegiate School in that city, and, having trained as a chemist, he worked for some time in the firm of Jonas, Meyer and Colver. In 1872 his father set up a works for the production of steel castings—a somewhat bold experiment for the times—and worked up a very successful business. In due course Sir Robert joined his father, and was only twenty-four years old when he took over the control of the firm; he succeeded his father on the death of the latter in 1888, the concern was converted into a limited liability company, and he became Chairman and Managing Director when he was no more than thirty years of age; he held these positions at his death.

Sir Robert's interest in alloy steels was aroused by reading a pamphlet describing the ferro-manganese alloys shown by the Terre Noire Company in Paris in 1878, and he commenced, in the laboratory belonging to his father's firm, his investigations on the effect of progressive additions of manganese on carbon steel. It was already known that small additions hardened the steel, but that when the manganese content reached about 3% the alloys became so brittle that they were useless. Sir Robert, however, raised the manganese content to much higher values, with the surprising result that when 12–13% was present an alloy with entirely novel properties was produced. This new steel became softer on being quenched, it was non-magnetic (despite its high content of iron), and offered a remarkable resistance to wear, the surface hardening under the influence of abrasion. This " manganese steel " of to-day was discovered in 1882; a full account of it was given to the Institution of Civil Engineers and the Iron and Steel Institute in 1888. The new material found extensive application in the construction of machine parts and objects liable to heavy wear, and it was also used in making the protective helmets introduced in the 1914–1918 war.

In the same systematic manner Sir Robert investigated the influence of silicon. In fact, his researches on the manganese and silicon steels had a common origin, for in 1882 he had noticed that a

pair of mill-pinions containing $1\frac{1}{2}\%$ of silicon had a grinding action on one another ; at that time he was searching for an improvement on the emery wheels of the day, which were liable to burst, and he hoped to make an abrasive alloy of steel. In his first experimental alloy he incorporated 4% of silicon and 8% of manganese, but it was not a success, so he tried the effects of additions of manganese and silicon separately. Silicon steel was originally developed solely with the idea of obtaining improved physical properties in the cast or rolled form, and large quantities were used for shipbuilding and structural purposes ; for example, it was used in the top-sides of the *Mauretania* and *Lusitania* on account of its high tensile strength. This research, however, also led to the introduction of the low-carbon silicon steels which possess such valuable electrical properties, including high resistance and low hysteresis, but it was not until about 1902, after years of patient research, that their exploitation began. Metallurgists all over the world took their share in this work, but to Sir Robert belongs the honour of having proved that silicon was not the bugbear that it had previously been considered to be.

While Sir Robert's name will always be associated more particularly with manganese steel and silicon steel, his interest was in no sense restricted to them only ; on the contrary, there is probably no aspect of steel metallurgy to which he did not devote his attention, and the researches carried out by him or under his direction were innumerable. To The Iron and Steel Institute alone he presented twenty-three papers (not counting his Presidential Address), and many more papers were published through a variety of other channels :

" On Manganese Steel " (*Journal*, 1888, No. I.).

" On Alloys of Iron and Silicon " (*Journal*, 1889, No. II.).

" Aluminium Steel " (*Journal*, 1890, No. II.).

" Alloys of Iron and Chromium " (*Journal*, 1892, No. II.).

" Notes on the Chicago Exhibition " (*Journal*, 1893, No. II.).

" The Results of Heat Treatment on Manganese Steel and their Bearing upon Carbon Steel " (*Journal*, 1894, No. I.).

" The Early History of Crucible Steel " (*Journal*, 1894, No. II.).

" The Production of Iron by a New Process " (*Journal*, 1895, No. II.).

" Alloys of Iron and Tungsten " (*Journal*, 1903, No. II.).

" Experiments relating to the Effect on Mechanical and other Properties of Iron and its Alloys produced by Liquid Air Temperatures " (*Journal*, 1905, No. I.).

" Sinhalese Iron and Steel of Ancient Origin " (*Journal*, 1912, No. I.).

" Method of producing Sound Ingots " (*Journal*, 1912, No. II.).

" On a New Method of revealing Segregation in Steel Ingots " (*Journal*, 1912, No. II.).

" Heating and Cooling Curves of Manganese Steel " (*Journal*, 1913, No. II.).

" The Magnetic and Mechanical Properties of Manganese Steel " (with B. Hopkinson, *Journal*, 1914, No. I.).

" Sound Steel Ingots and Rails " (with G. K. Burgess, *Journal*, 1915, No. I.).

" The Influence of Carbon and Manganese upon the Corrosion of Iron and Steel " (with J. Newton Friend, *Journal*, 1916, No. I.).

"Report on Fuel Economy and Consumptions in the Manufacture of Iron and Steel" (with W. A. Bone, F.R.S., and A. Hutchinson, *Journal*, 1919, No. II.).

"Fuel Control in Metallurgical Furnaces" (with R. J. Sarjant, *Journal*, 1919, No. II.).

"Further Communication on Temper-Brittleness of Nickel-Chrome Steel" (with R. H. Greaves and Miss M. Fell, *Journal*, 1919, No. II.).

"The Metal Manganese and its Properties : also Ores and the Production of Ferro-Manganese and its History" (*Journal*, 1927, No. I.).

"Alloys of Iron and Manganese containing Low Carbon" (*Journal*, 1927, No. I.).

"A Practical Trial of Roofing Sheets of Copper Steels and other Materials" (with S. A. Main, *Journal*, 1937, No. II.).

Sir Robert also enriched the literature of metallurgy with the following two books :

"Metallurgy and its Influence on Modern Progress" (1925 : Chapman and Hall, Ltd.).

"Faraday and his Metallurgical Researches, with Special Reference to their Bearing on the Development of Alloy Steels" (1931 : Chapman and Hall, Ltd.).

Sir Robert was the recipient of many honours from all parts of the world. In 1908 he was knighted, and in 1917 he was made a baronet. He was elected a Fellow of the Royal Society in 1909, and in 1925 he was made an Officer of the Legion of Honour ; he was the Master Cutler of Hallamshire in 1899, and in 1917 he received the Freedom of the City of London. He was made an honorary Doctor of Metallurgy by Sheffield University (1911), and an honorary Doctor of Science by Leeds University (1912) and by Oxford University (1927). Among the many medals, awards and premiums which he received the following may be mentioned : The James Forrest Premium of the Institution of Civil Engineers (1906), the Elliott-Cresson Gold Medal of the Franklin Institute (1910), the John Fritz Gold Medal of the Engineering Foundation (1921), and the Thomas Turner Gold Medal awarded by Birmingham University (1923), while the Société d'Encouragement presented him with their Gold Medal on three occasions, in 1890, 1893 and 1909.

Sir Robert was elected an Honorary Member of no less than twenty-seven scientific and technical institutions at home and abroad, including the Institution of Mechanical Engineers, the Institute of British Foundrymen, the Institution of Welding Engineers (now the Institute of Welding), the Worshipful Company of Blacksmiths, the American Institute of Mining and Metallurgical Engineers, the American Iron and Steel Institute, the American Society for Metals, the National Academy of Sciences, Washington, the Société des Ingénieurs Civils de France, the Institut de France (Académie des Sciences), the Royal Swedish Academy, the Société des Ingénieurs de Liége and the Japanese Iron and Steel Institute. Sir Robert was President of a number of institutions at various times and occupied this post of honour in the Faraday Society for

no less than seven years.   He was also a Liveryman of the Goldsmith's Company.

Sir Robert took a profound interest for many years in the work of The Iron and Steel Institute.   He was elected a Member of Council in 1890, and a Vice-President in 1895; in 1905 he commenced the two-year period of office as President.   The Bessemer Gold Medal was presented to him in 1904.

With the passing of Sir Robert Hadfield the iron and steel industry loses one of its most outstanding figures.   The Iron and Steel Institute mourns the death not only of a great metallurgist and industrial leader, but also of a good friend, for Sir Robert was one of the Institute's warmest supporters.   Sir Robert's membership dated from the year 1879, and thus another link with the past is severed.

The following appreciation of Sir Robert Hadfield was prepared by a member of his research staff :

The story of Sir Robert Hadfield's great achievements, both as an industrialist and as a metallurgist, has many times been told, and with his passing will no doubt be recalled by many well able to assess them.   The object here is rather to pay tribute to his personal qualities as revealed to those whose privilege it was to work with him in his metallurgical researches.

Life with him was certainly strenuous ; to the end of his career he worked sixteen hours a day and did not find it enough.   With his control of research activities dividing attention with the affairs of a large company, it can well be understood that the ordinary divisions of the day often counted for little, and that encroachment on their leisure hours was often the lot of members of his staff.

He has himself said that mere ability provides no guarantee of success—the royal road is hard work.   It was a conviction with him, too, that we humans require an irritation or spur to bring forth our best efforts.   Though to some these conditions may appear unenviable, they had the saving grace that Sir Robert spared himself no more than others.   It was quite usual for a batch of his shorthand notes, written in the quiet hours, to appear for attention at the commencement of the daily work.

As with other successful men, for him difficulties were made to be surmounted, and persistence in finding a way round was a prominent trait in his character.   With small difficulties or impediments, it was his way to clear them at once, and he did not spare the use of any resources, whether, for example, a long-distance telephone or a personal call, to that end.   It was so also with avoidable delays.

For many years his control of affairs in Sheffield had been exercised from his London address, a circumstance which might have proved an almost insuperable handicap to many ; yet with his abundant energy, aided by voluminous correspondence, telephone

messages and personal visits from the staff, the closest touch was always maintained even in the smallest details of research.

Although at an early age he had shown himself to be endowed with the true spirit of research and had established himself as a master in its pursuit, his procedure was by no means always orthodox. He had a great faith in intuition. In seeking an improvement or explanation of some known fact, his way therefore was rather by a direct shot. It must be admitted that with his wonderful insight he was justified, and more often than not was able to confound those who preferred the more tedious process of elimination.

Perhaps his most striking characteristic was his attention to detail. The ordinary record of an experiment would not serve, but every salient fact, however apparently insignificant, must be noted. Further, the information must be marshalled systematically, and presented in an orderly and clear fashion. He had an uncanny way of putting a wrong interpretation on an ambiguous statement; doubtless in many cases this was deliberate on his part, but it undoubtedly made for preciseness of statement. His thoroughness in this way made it difficult to train new members of the staff up to the necessary standard, but, having achieved it, no doubt was left in their minds as to its value. The recording of every circumstance, however small, which is the essence of good research, is, it is to be feared, not practised as generally as it might be.

Once a fact had been established by experiment, it must be rendered abundantly clear in its nature and implications, and with a correct sense of proportion. New facts had to be presented in many comparative tables, and if photographs, models or other aids could be useful, no trouble was spared in preparing them. As an example of establishing a true sense of proportion, he always insisted where necessary on photographs having a scale of dimensions or some familiar object incorporated, by which the size of the subject could be gauged. A similar course was taken with photomicrographs, in which ordinarily the indication—say, $\times 500$—quite fails, without concentration of thought, to give an adequate idea of the magnitude of the constituents.

This attention to detail and to clarity extended specially to the preparation of his papers for presentation and publication. The amount of work which was put into these—that is, apart from the experimental work itself—is perhaps hardly realised generally. The reader was always in view, and even at the risk of wearying the better informed, the endeavour was to make the presentation as clear and interesting as possible to those not so conversant with the subject. Attractiveness was cultivated in what might otherwise be a dull subject by—as he used to put it—" a little meat on the bare bones."

To achieve these ends, proof after proof was prepared and revised, sometimes reaching as many as ten or more, including typescript and printed proofs. The work naturally required the assistance of a very able clerical staff. Sir Robert did not lack for resources, but

lest it should be thought that in this he had a great advantage over many others, the quality of his papers, it must be said, was due much more to the personal effort which he put into them; he personally corrected each of the proofs in its turn until the final result was reached, and one cannot help feeling that a little more of the same consideration and study of the viewpoint of the reader might with great advantage be cultivated generally.

There was nothing haphazard, too, about the actual presentation of a paper. The necessary notes were carefully prepared for delivery, but specially a feature was made of exhibits giving ocular demonstration of the subject-matter. This was not mere showmanship. To Sir Robert, to present a paper for discussion without exhibits would, as he put it, have been to hold an inquest without the body. In this respect, also, he set an example which, it is to be feared, is not by any means followed to the extent that it might be.

The intensity of his researches reached its peak in his research on Faraday's steel and alloy specimens—a period of long-sustained and strenuous effort on the part of himself and his staff—he then being in his seventy-third year ! A research, too, in which, although the world largely gave him credit for the initiation of alloy steels, he took special pleasure in showing that the credit was due to the great Faraday for having been first in the field.

He had a profound respect—almost a veneration—for our large scientific and technical societies and institutions, and the brotherhood of his fellow-members was to him a real bond. He liked his staff to take part in their deliberations and in their administration, to the extent that one sometimes found it embarrassing when prompted by him to take part in a discussion among very prominent scientists, until reassured by their always kindly interest.

Pure science had a special attraction for him; he was an omnivorous reader of the scientific journals, and was particularly attracted to progress in the study of the atom and in the approach to the absolute zero of temperature. In all his work he felt that, much as had been learned of the properties of metals, we were far from arriving at the fundamentals, the secrets of which were locked up in the atom itself, and he did not readily bow down to this state of ignorance.

In referring to the literature, the amount which he perused was simply enormous, and can only be explained by his extraordinary faculty of getting straight to the points of special interest. Many cuttings came along each day with his markings, inviting our comments and at the same time giving his own in a very shrewd way. It was seldom that he had failed to notice any fact of importance.

In a personal way, Sir Robert was always the Chief, but work with him took on the nature of a companionship. A common interest in his ruling passion for research put anyone on friendly terms with him. He was always approachable, and welcomed frank expressions of opinion, even from junior members of the staff

whose work made them competent to express such opinions. If he found himself opposed to a consensus of opinion among his senior men as to a course of action, he could defer to them, but if his own convictions were too strong, his remark would be " I will take the responsibility," and, whatever the result, he honourably did so.

He liked to make public acknowledgment of the services of his scientific staff, and took a transparent pleasure in any honours which came to them. If illness overtook them he was most sympathetic.

That he was congenial to work with is borne out by the length of service of many of those on his staff, and he himself in 1933 publicly expressed his pleasure at finding that no less than fourteen of his principal colleagues had averaged thirty years with him.

We have lost a friend as well as a great chief and leader.

Sir HENRY CORT HAROLD CARPENTER, F.R.S., died suddenly on September 14, 1940, at the age of sixty-five; he succumbed to heart failure while on a country walk in the neighbourhood of Swansea. He came of a family which had produced several distinguished men, and, in the light of his own career, it is of interest to note that one of his great-great-grandfathers was the Henry Cort whose inventions proved so valuable to the iron industry of England and helped to give it its foremost position in the world. Sir Harold, however, was not originally trained as a metallurgist; he studied chemistry at Oxford and Leipzig, and became a research fellow and demonstrator at Owens College, Manchester.

In 1902 the National Physical Laboratory was founded, and Sir Harold was given charge of the chemical and metallurgical work there. In a short time a number of researches were put in hand and the reports published; the most important of these was the determination, in collaboration with B. F. E. Keeling, of the solidification range and the critical ranges of the iron-carbon alloys. Their results have stood the test of time, for the latest determination confirms their essential accuracy. Other subjects investigated included the aluminium-copper system, the heat treatment of high-speed tool steels, and complex alloys of iron.

In 1906 Sir Harold was appointed to the Chair of Metallurgy at the Victoria University of Manchester; in 1914, after a tour of metallurgical centres in the United States of America the object of which was to gain first-hand knowledge of the way in which industrial smelting processes were carried out there, he moved to the Royal School of Mines. Under his direction, both of these institutions became active centres of research; the subjects studied included the determination of the equilibrium diagrams of binary and ternary alloy systems, the growth of cast iron and the growth of metallic crystals after mechanical strain. This new method of preparing single crystals proved to have many advantages over the earlier process of solidification from the molten state, and he was

thus led to undertake, in collaboration with others to some extent, a study of the properties of single crystals and their modes of deformation, thus opening up a new and rich field of research. Other investigations dealt with the mode of separation of ferrite and pearlite from austenite in steels, and the structures of native copper and silver.

Many of the papers describing the results obtained in all these researches were published by The Iron and Steel Institute, of which the following is a list :

"The Freezing Point of Iron" (*Journal*, 1904, No. I.).

"The Range of Solidification and the Critical Ranges of Iron-Carbon Alloys" (with B. F. E. Keeling, *Journal*, 1904, No. I.)

"The Types of Structure and the Critical Ranges on Heating and Cooling of High-Speed Tool Steels under Varying Heat Treatment" (*Journal*, 1905, No. I.).

"Tempering and Cutting Tests of High-Speed Steels" (*Journal*, 1906, No. III.).

"The 'Growth' of Cast Irons after Repeated Heatings" (with H. F. Rugan, *Journal*, 1909, No. II.; 1911, No. I.).

"The Critical Ranges of Pure Iron" (*Journal*, 1913, No. I.).

"The Crystallising Properties of Electro-Deposited Iron" (with J. E. Stead, *Journal*, 1913, No. II.).

"The Hardening of Metals, with Special Reference to Iron and its Alloys" (with C. A. Edwards, *Journal*, 1914, No. I.).

"Some Experiments on the Reaction between Pure Carbon Monoxide and Pure Electrolytic Iron below the A_1 Inversion" (with C. Coldron Smith, *Journal*, 1918, No. II.).

"The Effect of Oxidising at Low Pressures on Heated Iron" (with Constance F. Elam, *Journal*, 1922, No. I.).

"The Production of Single Metallic Crystals and some of their Properties" (*Journal*, 1923, No. I.).

"The Metallography of some Ancient Egyptian Implements" (with J. M. Robertson, *Journal*, 1930, No. I.).

"The Formation of Ferrite from Austenite" (with J. M. Robertson, *Journal*, 1931, No. I.).

"The Austenite $\rightleftharpoons$ Pearlite Inversion" (with J. M. Robertson, *Journal*, 1932, No. I.).

"Structural Changes in Hypo-Eutectoid Steels on Heating" (with J. M. Robertson, *Journal*, 1933, No. I.).

As the theme of his Presidential Address to The Iron and Steel Institute in 1935 Sir Harold chose the subject "Alloys—Old and New." Shortly before the present war broke out in September, 1939, with Dr. J. M. Robertson he had completed a two-volume treatise on "Metals"; it covers a remarkably wide range, from crystal structure to industrial processes, and it will form an enduring monument to his work.

Despite his preoccupation with teaching, Sir Harold found time to give his services in other directions. He was Chairman of the Metallurgy Research Board and of the Gas Cylinders Committee, among other bodies. In 1929, when the Treasury set up a committee to enquire into the position of scientific staffs in Government departments, he was appointed Chairman; the "Carpenter Report,"

with its far-reaching recommendations, has served as the charter of the scientific side of the Civil Service. In later years he was called upon more and more to give advice on matters of scientific administration.

Many honours were conferred on Sir Harold. He was elected a Fellow of the Royal Society in 1918, and was knighted in 1929. He received honorary degrees from the Universities of Wales and of Sheffield, and was a corresponding member of the Royal Swedish Academy of Science and of the Société d'Encouragement, and was an honorary member of the American Institute of Mining and Metallurgical Engineers. He received the Carnegie Gold Medal in 1905 and the Bessemer Gold Medal in 1931 of The Iron and Steel Institute, the Institution of Mining and Metallurgy and the Thomas Turner Gold Medals, the Carl Lueg Gold Medal of the Verein deutscher Eisenhüttenleute, the Platinum Medal of the Institute of Metals, and, only this year, the Honda Gold Medal of the Japanese Institute of Metals.

When the present war broke out the Metallurgy Department of the Royal School of Mines was transferred to Swansea; here the Professor and his students found a new and happy home with Sir Harold's one-time pupil and collaborator, Principal C. A. Edwards, F.R.S.

Sir Harold had been a Member of The Iron and Steel Institute for thirty-six years, for his election took place in 1904. In 1923 he was elected a Member of Council, and in 1926 he became Honorary Treasurer. In 1935 he commenced the two-year period of his office as President, and thus achieved the unique distinction of having occupied the Presidential Chair of all the three societies connected with his science, namely, The Iron and Steel Institute, the Institute of Metals and the Institution of Mining and Metallurgy.

HUBERT SPENCE THOMAS died suddenly on January 16, 1940, at Los Angeles, U.S.A. Born in 1871 in the Forest of Dean, he was the seventh son of the late Mr. Richard Thomas, of Lydbrooke, Gloucestershire, the founder of Messrs. Richard Thomas & Co., Ltd. He received his education at Dulwich College. In 1887 he entered the Lydbrooke Tin-Plate Works as an apprentice; his training here was particularly thorough, and, largely as a result of his intimate knowledge of the practical side of the manufacture of tinplate, he was subsequently associated with many of the technical developments in the industry in South Wales.

In 1898 Mr. Spence Thomas was called upon to undertake the management of the South Wales Steel and Tin-Plate Works, Llanelly; later he started up the Cwmbwrla Tin-Plate Works, Swansea, and still later the Burry Tin-Plate Works at Llanelly. In 1907 he became the general manager of the tinplate works of the Melingriffith Co., Ltd., near Cardiff, where he remained for over twenty years, and where, in collaboration with his partner,

Mr. W. R. Davies, many important technical developments in manufacturing methods were introduced.

Mr. Spence Thomas lived at Cardiff until about three years ago—he had some years before disposed of his interests in the tinplate industry—when he visited America, where he had since lived. At the time of his death, he was chairman of the Wolverhampton Steel and Iron Co., Ltd.

Mr. Spence Thomas took a great interest in the technical and commercial development of the South Wales industry. In 1899 he joined the South Wales Institute of Engineers, to the proceedings of which he made numerous contributions; in 1925 he served as its President, and in 1932 was made an honorary member. He was an executive member of the Welsh Tinplate Makers' Association. At one time he was chairman of the National Food Canning Council executive; in 1925 he became a member of the Institution of Mechanical Engineers, and in 1935 he was a member of the Institute of British Foundrymen's delegation to the American International Foundry Conference. He was a Freeman of the City of London, a member of the Glamorgan County Council and a Justice of the Peace for that county.

Mr. Spence Thomas was a warm supporter of The Iron and Steel Institute, which he had joined in 1897; he was a frequent attendant at the Meetings, and his contributions to the discussions on papers dealing with tinplate manufacture and ancillary subjects were always of interest. He was elected a Member of Council in 1926, a Vice-President in 1933 and an Honorary Vice-President in 1938.

FREDERICK BEST died on August 12, 1940, at his home at Ross-on-Wye; he was seventy-four years of age. He had been engaged in the steel industry since 1882, when he began work with Messrs. William Jessop and Sons, Ltd., Sheffield. He stayed for over twelve years with this company, until, in 1895, he was appointed head of the steel foundry department of Messrs. Thos. Firth and Sons, Ltd., Sheffield, of which company he became secretary in 1902, special director in 1909, and, finally, director of the Tinsley steel department. During this career he travelled widely on behalf of his firm, in the United States, Canada, Russia and other European countries. In addition to his duties as director and secretary he acted also as the nominee director of Messrs. Thos. Firth and Sons, Ltd., on the boards of the Firth-Brearley Stainless Steel Syndicate, High Speed Alloys, Ltd. (of Widnes), and Firth-Derihon Stampings, Ltd.

When the last war broke out, he took an active part in the arrangements for producing tungsten powder, which previously had been entirely imported from Germany. Besides he acted as honorary secretary of the Aircraft Steelmakers' Committee, and the Ministry of Munitions appointed him a member of the Advisory Committee charged with the duty of arranging for the supply of high-speed steel to the allies.

In 1922 he left Messrs. Thos. Firth and Sons, Ltd., to become commercial manager of Messrs. Bolckow, Vaughan and Co., Ltd., Middlesbrough.

Mr. Best was for many years a member of the Sheffield Chamber of Commerce, the Federation of British Industries and the Society of British Aircraft Constructors.

Mr. Best was elected a Member of The Iron and Steel Institute in 1904.

Colonel ROOKES EVELYN BELL CROMPTON, C.B., F.R.S., died at his home, Azerley Chase, Ripon, on February 15, 1940; he was in his ninety-fifth year. Born at Sion Hill, Yorkshire, on May 31, 1845, he entered the Navy at a very early age, and, having seen active service as a cadet, was awarded the Crimea Medal and Sebastopol Clasp when only eleven years old. On returning to England he left the Navy, and in 1856 was sent to Elstree to prepare for Harrow (1858), which he left in 1860. In 1864, having served for some time under Sturrock, of the Great Northern Railway, at Doncaster, he joined the Rifle Brigade, and in the following year went to India. While still in England he had been working on the construction of the *Blue-Bell*, a steam-driven road locomotive. His tools and the parts of this uncompleted engine were sent out to him, and he finished it and made it work. The outcome of this was that in 1870 he was seconded from his regiment to become superintendent of the Government Steam Train Department. In 1875, in accordance with Army regulations, he had to return to his regiment, and he was awarded a special grant in recognition of his services in connection with steam-propelled road transport. He came back to England, and in 1876 was gazetted out of the service with the rank of Captain.

In the same year he entered into partnership with Messrs. T. H. P. Dennis & Co., of Chelmsford, then specially interested in a new form of valve for use in heating apparatus. To supplement his income from this source, he practised independently as an engineer for some time, and helped the late Mr. Peter Willans in designing tramcars fitted with the latter's engines. In 1878 he laid out a foundry for the Stanton Ironworks, and later was given a seat on the board of the company. Trouble was experienced in the lighting of the works for night shifts, so Colonel Crompton, with his fellow-directors' concurrence, installed Gramme generators and arc lamps, with complete success. This achievement prompted him to take up the manufacture of electrical machines, and he founded the firm of Crompton and Co. (later to become Messrs. Crompton, Parkinson & Co., Ltd.), with headquarters at Chelmsford; he obtained the sole rights to make and sell Bürgin-type dynamos. As the generators could supply from six to eight arc lamps in series, the firm was able to undertake the lighting of railway stations, such as St. Enoch's, Glasgow, goods yards, docks and other open spaces

where night work was carried on. During 1879 many portable electric lighting sets were designed, which, combined with the first Willans high-speed compound engine, gave remarkable results; about Christmas time of this year Colonel Crompton lighted up his own home, using small arc lamps fixed in his dining- and drawing-rooms—probably the first instance of the effective illumination of a private house by electricity.

In 1880 he became associated with Swan, who had invented a carbon-filament incandescent electric lamp, and it was apparent to him that this presented the solution of the problem of interior illumination. He was commissioned to instal the lamps at the Glasgow Post Office and Queen Street Station; he applied them in his own house in 1881, and in 1883 he put in the first large installation, running to 1600 lamps, in the Law Courts. He also put in electric light at Buckingham Palace and Windsor Castle.

The great fire which destroyed the Ring Theatre in Vienna in 1883 so impressed the dangers of gas on the Emperor Franz Joseph that he requested the gas company then supplying Vienna to consider whether the Opera House and other Imperial theatres could not be better and more safely illuminated by electricity; in due course, Colonel Crompton was called into consultation, and in 1885 he spent some weeks in Vienna on this problem. In the meantime he was pushing on with the idea of the supply of current for house lighting in London, and took the first steps towards the formation of the Kensington Court Electric Lighting Co., afterwards the Kensington and Knightsbridge Electric Lighting Co., one of the earliest, if not the first, public lighting undertakings.

Between 1886 and 1888 a Corps of Electrical Engineers was formed as a volunteer branch of the Royal Engineers, and shortly after the outbreak of the Boer War in 1889, Colonel Crompton, as officer in command, was asked to take a detachment to South Africa; he was mentioned in despatches, gained the Queen's Medal and was made a C.B. The splendid services of the unit brought its commanding officer to the notice of Lord Roberts, who, remembering the work on steam road vehicles in India a quarter of a century before, appointed the Colonel to reorganise the Mechanised Transport Corps, in which connection he returned to England in 1900 and took up the design of lighter traction engines. This served to quicken his interest in mechanical road transport; in 1910, when the Road Board was formed, he became its engineer, and made many investigations on the tendency of various forms of vehicle to raise dust, means of preventing this (tar-spraying), and the wearing properties of various road construction materials.

During the Great War he rendered many services to his country. He was concerned in the standardisation of the screw threads of projectiles to ensure interchangeability; he served on a committee appointed by Mr. Churchill in 1915 to devise vehicles capable of crossing trenches, and he also studied various types of chain and other

tracks, special steel plates to resist rifle fire, engines to propel the vehicles and many other matters.

Colonel Crompton was a Fellow of the Royal Society; he was twice President of the Institution of Electrical Engineers, and in 1926 received the Faraday Medal presented by that body; he was a member of Council of the Institution of Civil Engineers and a member of the Institution of Mechanical Engineers; he was a Past President of the Junior Institution of Engineers and of the Commercial Motor Users' Association, and the first President of the Institution of Automobile Engineers; he was a founder member of the Royal Automobile Club. He sat on innumerable technical commissions, Government advisory bodies and international committees.

Colonel Crompton's association with The Iron and Steel Institute had been a long one, for he took up membership in 1892.

JOSEPH PERCIVAL GILLOTT, who had been in failing health for some months, died on February 19, 1940, at Hornsea, at the age of fifty-eight. He was a director of Messrs. Marple and Gillott, Ltd., Sheffield, and of the Burton Constructional Engineering Co., Ltd., Burton-on-Trent; he was widely known in the scrap metal industry.

Mr. Gillott was elected a Member of The Iron and Steel Institute in 1913.

JOHN GJERS died on July 2, 1940, at his home in Middlesbrough, aged fifty-one. He was managing director of Messrs. Gjers, Mills and Co., Ltd., pig iron manufacturers, of Ayresome Ironworks, West Marsh, Middlesbrough, which had been founded by his grandfather.

Mr. Gjers joined The Iron and Steel Institute in 1929.

THOMAS EDWARD HOLGATE, A.R.S.M., died on February 7, 1940, at the age of eighty-five. He was educated at Liverpool College and the Royal School of Mines, and became a pioneer in the manufacture of ferro-manganese in the blast-furnace. He was a director of the Darwen and Mostyn Iron Co., Ltd., with which company he was associated for sixty-two years.

Mr. Holgate was a well-known personality in the town of Darwen and over a long period was active in various public capacities, including that of the mayoralty. In 1936, in recognition of his work and philanthropy, he was given the freedom of the borough.

Mr. Holgate was a very old Member of The Iron and Steel Institute, having been elected in 1887.

ALFRED CECIL LEWIS, of Newport, Mon., died on January 27, 1940; he was only thirty-eight years old. Born at Talybont, near Usk, he was educated at Monmouth Grammar School and Birmingham University, where he obtained his training in engineering. From

the University he went to the Ebbw Vale Steel Works and became assistant manager of the mill and the Bessemer plant. In 1931 he joined the firm of Messrs. Cordes (Dos Works), Ltd., nail manufacturers, of Newport, Mon., and was later appointed joint managing director, which position he held at the time of his death. Mr. Lewis was a Member of Council of the Newport Chamber of Commerce. He joined The Iron and Steel Institute in 1925.

DANIEL CONNOR LYSAGHT died on May 15, 1940, at the age of seventy-one. He was managing director of the Orb Works of Messrs. John Lysaght, Ltd., Newport, and was also a director of Messrs. Joseph Sankey and Sons, Ltd.

Mr. Lysaght had long been a Member of The Iron and Steel Institute, for his election took place in 1904.

WALTER CREALOCK MACARTNEY died suddenly on March 9, 1940, at his home, Ashgate House, Chesterfield. He was born in Devonshire in 1876, and was educated at the Dragon School, Oxford, and the Oxford Military College. On leaving school, in 1893, he was entered as a pupil at the Elswick works of Sir W. G. Armstrong, Whitworth and Co., Ltd. In the gunnery and gunmounting department of these works practically the whole technical evolution of naval-gun and gun-mounting design of that period took place. Mr. Macartney remained on the staff after the completion of his apprenticeship. He was one of the subalterns who accompanied the Elswick Battery to South Africa during the Boer War. He served through the whole of that campaign and was promoted Captain. On his return he rejoined his firm. In 1907 he took up employment with the Atlas Works of Messrs. John Brown and Co., Ltd., Sheffield. This firm, together with Messrs. Charles Cammel & Co., Ltd., had a short time before founded the Coventry Ordnance Works. On account of his great experience in the manufacture of guns and their mountings, Mr. Macartney was, in 1909, appointed first works manager of this establishment and soon afterwards general manager. The immense output of guns and mountings from these works during the war of 1914–1918 was largely due to his organising abilities. On the cessation of hostilities the Coventry Ordnance Works were closed, and Mr. Macartney joined Messrs. Walter Somers & Co., Ltd., Halesowen, as joint managing director. He was invited by the Government to undertake the supervision of Woolwich and other national armament factories, but declined the proposed appointment. Instead, in 1924, he returned to Sheffield as general manager of Sheffield Steel Products, Ltd., during the reorganisation of that firm, and three years later he transferred to Chesterfield on his appointment as managing director of Messrs. Markham & Co., Ltd., which position he held at the time of his death.

Mr. Macartney was much concerned with the welfare of the men

in his employ. He took a keen interest in the Staff Benefit Society, and acted as chairman of this organisation from 1927 until its absorption, in 1939, into the Foremen's Mutual Benefit Society. He served for many years on the Executive Council of the latter society and was for some time its vice-chairman. In addition, he was a trustee of the Dyer Memorial Fund, a member of the Management Committee of the Sheffield and District Engineering Employers' Association, and a past-president of the Chesterfield Chamber of Commerce. He was an associate of the Institution of Naval Architects and a member of the Junior Institution of Engineers, of which he was president in 1931–1932. A short time before his death he was appointed a member of the Iron and Steel Committee under the Ministry of Supply.

Mr. Macartney was elected a Member of The Iron and Steel Institute in 1920.

Dr. CHARLES HESTERMAN MERZ, together with his son and daughter, were killed in October, 1940, as a result of enemy action. Born in 1874 at Gateshead-on-Tyne, he was the son of Dr. J. Theodore Merz, the author of the " History of European Thought in the Nineteenth Century." He was educated at Bootham, York, and at Armstrong College, and received his practical training at Newcastle, Lincoln, London, in Ireland and other places. In 1898 he acted as engineer for the promotion of a Bill for supplying electric power to works and shipyards on Tyneside. This was the first of the so-called Power Bills. Afterwards he was employed as an engineer with the first company to use three-phase distribution in England. This company, which, after amalgamation in 1900 with the Newcastle-upon-Tyne Electric Supply Co., Ltd., became the North Eastern Electric Supply Co., Ltd., expanded during the succeeding eight years, until it covered Northumberland, Durham and parts of Yorkshire. During this period he devoted much time to developing the electrification of collieries and iron and steel works, which included the use of the first large Ilgner sets. In 1903 he electrified the Tyneside lines for the North-Eastern Railway. At the same time he designed the Carville power station, and the low cost of production there led to the preparation of a comprehensive scheme of large power stations situated on the Thames, which resulted in the promotion of the London Power Bill in 1905. About this time he took Mr. William McLellan into partnership, thus founding the well-known firm of Merz and McLellan. In the following years he visited Australia, India, the United States, South Africa and the Argentine, being engaged on numerous problems in connection with power supply and railway electrification in these countries. During the War of 1914–1918 he was Director of Experiment and Research to the Admiralty and, at the same time, served on the Haldane and Williamson Committees, which recommended the appointment of the Electricity Com-

missioners. In 1925 he put before these Commissioners a memorandum the outcome of which was the appointment of the Weir Committee, the report of which led to the Act of 1926 setting up the Central Electricity Board and to the construction of the " Grid." Dr. Merz was to have placed gratuitously his great and varied experience at the service of the Ministry of Supply from October 28 of this year.

Dr. Merz was a vice-president of the Institution of Electrical Engineers during 1912–1915. He was awarded the Faraday Medal in 1931, and in 1932 he received an honorary D.Sc. from the University of Durham. He was a member of the Institution of Civil Engineers and a Fellow of the American Institute of Electrical Engineers. In the course of his career Dr. Merz published numerous papers, one of which, " Power Supply and its Effect on the Industries of the North-East Coast," was read before The Iron and Steel Institute in 1908. He joined the Institute in 1909.

JOHN MARTIN MOORWOOD, the governing director of Messrs. John M. Moorwood, Ltd., died on April 8, 1940; he was seventy-eight years old. He was the second son of Mr. T. P. Moorwood, one of the founders of Messrs. Marshall, Watson and Moorwood, a Sheffield firm of ironfounders. After a period with this firm, Mr. Moorwood founded his own works, to which he gave his name, for the production of chilled, grain and special alloy rolls. He was connected with the Sheffield Chamber of Commerce for over twenty years and had been president of the Sheffield Ironfounders' Association since 1931. He was a Freeman of the Cutlers' Company.

Mr. Moorwood joined The Iron and Steel Institute in 1930.

WILLIAM ISAAC PEACH of Sheepbridge, near Chesterfield, died on January 17, 1940, aged sixty-four. A native of Codnor Park, he served his apprenticeship at the works of the Butterley Co., Ltd., and for thirty-three years was manager of the forge and rolling mills of the Sheepbridge Coal and Iron Co., Ltd. He was an associate of the Staffordshire Iron and Steel Institute, a member of the Sheepbridge Managers' and Foremen's Association and treasurer of the Sheepbridge Ambulance Division.

Mr. Peach joined The Iron and Steel Institute in 1923.

ALFRED JOHNSON RAINE died on March 1, 1940, at his home at Morpeth, aged fifty-six. He was chairman and managing director of Messrs. Raine & Co., Newcastle-on-Tyne and Derwenthaugh; he was associated for forty years with this firm, which had been founded by his father, Mr. B. Raine, together with Mr. G. Raine.

In the Great War Mr. Raine was a Captain in the 9th Durham Light Infantry and was badly gassed at Ypres.

Mr. Raine became a Member of The Iron and Steel Institute in 1926.

OSCAR FRIDOLF ALEXANDER SANDBERG, O.B.E., M.Inst.C.E., died in London on February 15, 1940, aged sixty-one. He was educated at Dulwich College and University College, London. After two years in the testing department of Messrs. Willans & Robinsons, Ltd., Rugby, and two years with Messrs. Dick, Kerr & Co., he was taken into partnership with his father, who was then the consulting engineer for permanent way to the Canadian, Swedish, Chinese and Siamese Government Railways. During the Great War, acting for his firm, Mr. Sandberg supervised the testing and inspection of over one million tons of railway material which was being manufactured, in the United States of America, for the French Government and other French railways. In addition he was Steel Consultant of the British Ministry of Munitions for work in Canada and the United States from 1916 to 1918 ; in recognition of this work he was awarded the O.B.E. In collaboration with his brothers, Mr. C. P. Sandberg, C.B.E., and the late Mr. N. P. P. Sandberg, C.B.E., he developed the well-known processes of sorbitic treatment of rails and tyres, and the controlled oven-cooling of rails.

He had long been a Member of The Iron and Steel Institute, for his election took place in 1914.

LEONARD WALTON SCHUSTER died on July 6, 1940, at Camberley, Surrey, aged fifty-nine years. Born at Denton, he was educated at Eastbourne College and Trinity College, Cambridge. In 1903, having taken his degree in mechanical science, he commenced his apprentice-ship with Messrs. James Simpson & Co. and the Brush Electrical Engineering Co., Ltd. In 1906 he was appointed charge engineer to the Leamington and Warwick Electric Power and Lighting Co., Ltd. He then became a designer and head of the testing depart-ment of the New British Electric Supply Co., Ltd., and afterwards worked in the contract department of the Brush Electrical Engineer-ing Co., Ltd. In 1909 he was employed, as an assistant engineer, by the English Sewing Cotton Co., Manchester, with which firm he remained until 1920, when he took up employment with the British Engine, Boiler and Electrical Insurance Co., Ltd., and became the chief research engineer of the company. At the time of his death he was engaged on work for the Admiralty at Portsmouth. He was the editor of his company's annual report on mechanical breakdowns of engine and boiler plant and, in addition, contributed many articles to the technical press. The Institution of Mechanical Engineers awarded him the Thomas Hawksley Gold Medal in 1933 for the best paper of the year, and in 1935 the Bernard Hall Prize for a paper on fusion welding of boilers. To The Iron and Steel Institute he sub-mitted the following papers : " The Effects of Contamination by Nitrogen on the Structure of Electric Welds " (1930), and " The In-fluence of the More Common Elements in Inhibiting Needles in Nitrogen-Rich Steels and Arc Welds " (1932). He also contributed

two papers to the Symposium on the Welding of Iron and Steel, which was organised by the Institute in 1935, *viz.*, "Note on the Use of the Tensometer in Detecting Weldability of Weld Metal" and "Some Important Considerations in the Preparation of a Specification for a Welded Boiler." At this Symposium and also at other meetings of the Institute Mr. Schuster made numerous contributions to the discussion of papers on a variety of subjects.

He was a member of the Institution of Mechanical Engineers and the Institution of Electrical Engineers, and a past-president of the Manchester Metallurgical Society. He was elected a Member of The Iron and Steel Institute in 1925.

FRED SMITH, C.B.E., of Pollard Hall, Gomersal, near Leeds, died suddenly on May 3, 1940, at Lytham, where he had been staying after an illness; he was sixty years old. He had become associated with the engineering industry at an early age and took an active part in the management of several leading firms. He was chairman of Messrs. J. Blakeborough & Sons, Ltd., of Woodhouse Works, Brighouse, Yorkshire, and joint managing director of British Ropes, Ltd., Carr Hill, Doncaster. He was also a director of Temple-borough Rolling Mills, Rotherham; Messrs. William Cooke & Co., Ltd., Tinsley Steel, Iron and Wire Rope Works, Tinsley, Sheffield; and Darlington Fencing Co., Ltd., Darfen Works, Carr Hill, Doncaster.

On account of his intimate knowledge of the wire industry he had been appointed Controller of Wire under the Ministry of Supply, which position he held until his illness. During the last war he performed a similar service as Assistant Director (Wire) of Materials and Priority, in the Controller's Department at the Admiralty; in recognition of his work he was awarded the C.B.E. at the conclusion of the war.

Mr. Smith had for many years been a member of Council of the Federation of British Industries. He was a magistrate for the West Riding of Yorkshire.

Mr. Smith was elected a Member of The Iron and Steel Institute in 1914.

GEORGE HENRY STRICK died on May 3, 1940, at Cheltenham, in his eighty-sixth year. He was born on December 26, 1854, and was educated at Swansea Grammar School and Winchester College, and from 1872 to 1874 studied chemistry at Dresden Technical University. He then went to France and worked at the Terre Noire Steelworks, under the guidance of Alexandre Pourcel, the friendship with whom he retained until Pourcel's death, sixty years later. In 1875 he returned to England and, after a short period at the Dowlais Works, joined his father in the management of the Amman Iron and Tinplate Works at Brynamman. The pig iron produced at these works was then largely used for the manufacture of charcoal bars,

a trade which ceased about 1882, when charcoal bars were no longer made. In the following years Amman pig iron was mainly supplied to the makers of chilled rolls, both in South Wales and in the Midlands. In 1891, however, the works closed down owing to changing circumstances, in particular the introduction of steel in the place of wrought iron. Mr. Strick remained the manager of the tinplate works until that also ceased working in 1897. He then went to Ystalyfera to take over the management of the Gyrnos Tinplate Co., Ltd., which he retained until 1923, when he retired from active work and went to live in Cheltenham; he remained, however, a director of the company.

In the course of his career Mr. Strick held a number of public appointments. From 1878 to 1896 he was a member of the Llandovery Board of Guardians. He was appointed a magistrate for the County of Glamorgan in 1882, for Carmarthen in 1883 and for Breconshire in 1909, and he was one of the first magistrates to form the newly constituted Petty Sessional Division at Ammanford. He was a member of the Licensing Committee of the County of Glamorgan for some years after the passing of the Licensing Act in 1904, and he later became, for some years, a member of the Standing Joint Committee.

Mr. Strick was a warm supporter of The Iron and Steel Institute; he was also one of the oldest members, for his election took place in 1876.

HARRY BROOKS TOY, well known in industrial circles on Teesside, died at his residence, The Ridge, Saltburn-by-the-Sea, on February 26, 1940. A native of West Bromwich, he was trained as a mechanical engineer at the Birmingham works of Messrs. Tangyes, Ltd.; from there he went to Messrs. Bolckow, Vaughan & Co., Ltd., Middlesbrough, and later to Messrs. Thomas Perry & Son, Ltd., Bilston, where he was employed as head draughtsman and assistant manager. He was then appointed managing director of Messrs. C. Akrill & Co., Ltd., West Bromwich, which position he held for five years. In 1907 he returned to Tees-side and founded the British Chilled Roll and Engineering Co., Ltd., at Haverton Hill. He remained chairman and managing director of his company until his retirement, a few years ago. He was also a director of Messrs. H. E. Woolley, Ltd., and of Messrs. Wrights Chilled and Grain Roll Co., Ltd.

Mr. Toy was a Past-President of the Tees-side Chamber of Commerce, of the Staffordshire Iron and Steel Institute, of the Cleveland Technical and Scientific Institute, and of the Cleveland Institution of Engineers; during his Presidency of the last-named body, in 1924, he was an Honorary Member of Council of the Iron and Steel Institute as the representative of the local society. He represented the Institute on the British Standards Institution Sub-Committee on Cast Iron.

Mr. Toy was a warm supporter of The Iron and Steel Institute, and was a familiar figure at the meetings; he had been a Member for nearly fifty years, for his election took place in 1892.

GEORGE ETHELBERT WOLSTENHOLME died on July 3, 1940, at Sandsend, near Whitby.   Born in Sheffield in 1875, he received his education in that city, at All Saints School and afterwards at the Sheffield Technical School.   In 1890, on leaving school, he was apprenticed to the engineering and boilermaking firm of Messrs. Hawksley, Wild & Co., Ltd., with whom he remained for a short time after the completion of his apprenticeship.   He was then appointed works engineer to Messrs. John Holding & Co., Ltd., engineers and forge-masters, Sheffield, whose plant he reorganised extensively.   In 1897 he left this employment to become representative in Lancashire and Yorkshire of Messrs. William Parkin & Co., Ltd., of the Crown Steel Works, Sheffield, and from that time onwards he was engaged on the commercial side of the steel industry. In 1906 he was appointed to represent Messrs. Thos. Firth & Sons, Ltd., in the North Midlands, and thus he began his long association with stainless steel, of which he made a special study from 1914 onwards.   In 1917 he visited the United States to demonstrate the possibilities of stainless steel and to superintend the introduction of its manufacture at the works of the Firth Sterling Company, the Bethlehem Steel Corporation, the Carpenter Steel Company, and the Washington Steel and Ordnance Company.   On his return to Sheffield he was appointed director of the Firth-Brearley Stainless Steel Syndicate, Ltd., and manager of the stainless-steel department of Messrs. Thos. Firth & Sons, Ltd.   In 1922 Mr. Wolstenholme was elected a member of the Institution of Mechanical Engineers.   He had been a Member of The Iron and Steel Institute since 1910.

SECTION II.

A SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL, AND KINDRED SUBJECTS.

CONTENTS.

The Editor has been assisted in the preparation of this Survey by
R. A. RONNEBECK.

MINERAL RESOURCES

The Coal Resources of the Southern Portion of the Maitland-Cessnock-Greta Coal District. L. J. Jones. (New South Wales Department of Mines Geological Survey, 1939, Mineral Resources No. 37). The author was instructed by the Australian Government to re-examine a portion of the New South Wales coalfield previously studied by David in 1907. The present author's field work was completed in 1927 and his final report is now presented.

The Application of Geophysics in the Salzgitter District. B. Brockamp. (Metall und Erz, 1940, vol. 37, Jan., No. 1, pp. 1–6). The author describes the results of geophysical investigations of the Salzgitter iron-ore deposits.

The Manganese Ore Beds of Western Bulgaria. W. E. Petrascheck. (Metall und Erz, 1940, vol. 37, Mar., pp. 101–104). The author presents a brief geological survey of the occurrence of manganese ores to the northwest and east of Sofia. In some places the average manganese content is 38% and in others 46%.

Geology and Coal Resources of the Minot Region North Dakota. D. A. Andrews. (United States Geological Survey, 1939, Bulletin 906-B).

Reconnaissance of Mining Districts in Churchill County, Nev. W. O. Vanderburg. (United States Bureau of Mines, 1940, Jan., Information Circular 7093). The author reports on a survey of the occurrence of minerals in Churchill County, Nevada, which was undertaken in 1938 and 1939.

The Mizpah Coal Field, Custer County, Montana. F. S. Parker and D. A. Andrews. (United States Geological Survey, 1939, Bulletin 906-C). The authors present a detailed geological survey of the Mizpah coalfield in southeastern Montana.

The Coal Resources of McCone County, Montana. A. J. Collier and M. M. Knechtel. (United States Geological Survey, 1939, Bulletin 905).

Geology and Fuel Resources of the Southern Part of the Oklahoma Coal Field. Part 4.—The Howe-Wilburton District, Latimer and Le Flore Counties. T. A. Hendricks. (United States Geological Survey, 1939, Bulletin 874-D).

ORES—MINING AND TREATMENT

A Review of Certain Unit Processes in the Reduction of Materials.
J. C. Farrant. (Institution of Chemical Engineers, Apr., 1940,
Preprint). The author discusses all aspects of the dry and wet
methods of crushing, screening, grinding and classifying different
minerals, and shows that the increased efficiency achieved is the
result of a combination of factors including simplification of design,
adaptation of auxiliary equipment, increasing use of metal alloys in
machine construction and of rubber for handling abrasives and acid
pulps, and a greater use of automatic control of feed rate, pulp
densities and particle size.

**Contribution on the Beneficiation of Siegerland Spathic Iron Ore
Sludges.** W. Luyken and E. Ellerich. (Stahl und Eisen, 1940,
vol. 60, Feb. 8, pp. 109–116). There are two ore-concentration
plants at the Füsseberg Mines in Siegerland for preparing the spathic
iron ores, each handling about 600 tons per day, and at these plants
there is a loss of 1–2% in the form of sludge containing about
24% of iron and 4–5% of manganese. In this paper the authors
describe an investigation of methods of recovering the iron from this
sludge, in the course of which it was found that a magnetising-
roasting process using a rotary kiln on a semi-technical scale was the
most successful. They compare the different methods and discuss
the economic aspects of the processes.

A New Method for the Treatment of the Styrian Spathic Iron Ores.
W. Luyken and L. Heller. (Metall und Erz, 1940, vol. 37, No. 5,
pp. 81–88). The authors give a detailed account of the favourable
results they obtained when applying their method of magnetising
roasting (*see* Journ. I. and S.I., 1940, No. I., p. 65 A) to Styrian ores.
These contain iron in the form of carbonate which form a continuous
series of solid solutions with the carbonates of calcium and
magnesium.

Thirty Years of Iron Sintering. E. W. Shallock. (Blast Furnace
and Steel Plant, 1940, vol. 28, Jan., pp. 71–75; Feb., pp. 169–170).
After a general consideration of the benefits, both economic and
technical, which can be obtained by the sintering of ore fines and
blast-furnace flue dust, the author notes two classes of characteristics
of ores which depreciate their value and can be corrected by sinter-
ing. In the first class are those which render the ore physically or
chemically unfit for sintering, and in the second are those which
contribute to a prohibitive cost of delivery to the blast-furnace.
He next divides these two classes into a number of specific character-
istics and examines a number of United States ores in the light of this
classification. In the concluding part of his paper he surveys the
growth in the production of sinter in America since 1911.

REFRACTORY MATERIALS

Cannock Chase Refractory Brickworks. (Iron and Coal Trades Review, 1940, vol. 140, Apr. 19, pp. 615–616). A brief illustrated description is given of the modern brickworks at Hednesford of the Cannock Chase Colliery Co., Ltd., where red bricks, tiles and refractory bricks are now being made.

Fused Magnesia. B. Moore. (Transactions of the British Ceramic Society, 1940, vol. 39, Feb., pp. 41–51). The author points out that if magnesite, or magnesia obtained by calcining magnesite, is heated at a temperature of 3000° C. fused magnesia is obtained, which is practically pure β-magnesia (periclase), composed of crystals of the cubic system, octahedral in form. Fused magnesia may be considered as magnesia which has attained its maximum degree of shrinkage and, therefore, offers more stability than varieties of magnesia prepared at lower temperatures. This property is of particular value for high-temperature basic refractory bricks and furnace linings because of the stability and low shrinkage of the material when used as grog. Compared with magnesia prepared at lower temperatures the fused material shows an increase in electrical resistance, thermal conductivity, hardness and chemical inertness. The author gives detailed information on the physical and chemical properties of fused magnesia, including data on the melting point, volatilisation temperature, specific gravity, thermal and electrical conductivity, thermal expansion, hardness, refractive index and the behaviour of solid solutions formed with ferrous and ferric oxides. Finally, he deals with the industrial application of fused magnesia with particular regard to its use for the production of bricks and crucibles. He gives tables of data on the apparent porosity, linear contraction, refractoriness-under-load, cold crushing strength and resistance to spalling of fused-magnesia bricks prepared in different ways.

Five Years of Progress in Steelworks Refractories.—The Open-Hearth Furnace. J. H. Chesters. (Iron and Steel, 1940, vol. 13, Apr., pp. 214–220). The author reviews the progress made during the last five years in the development of refractory bricks for open-hearth furnaces. He stresses the importance and benefits now attached to the use of pyrometers, especially in the furnace roof.

FUEL

The Fuel Question at Swedish Ironworks. M. Tigerschiöld. (Jernkontorets Annaler, 1939, vol. 123, No. 12, pp. 559–569). (In Swedish). The author reviews the fuel economy at a number of Swedish iron and steel works, comparing the present position with that in 1913.

Some Physical Characteristics of Coal and Phenomena Observed During the Combustion of Coal. F. S. Sinnatt. (American Chemical Society : Fuel in Science and Practice, 1940, vol. 19, Jan.-Feb., pp. 5–7 ; Mar., pp. 38–42). In the first part of his paper, the author discusses the influence of the porous structures of various coals on their combustion properties. In the second part he refers to the fact that when certain powdered coals are allowed to enter a hot inert atmosphere, or one deficient in oxygen, the particles are converted into hollow spheres (cenospheres) ranging in volume up to 40 times that of the original coal particle. He considers how the size of these cenospheres varies according to the temperature and the kind of coal. In conclusion he gives the results of experiments which indicate how the rate of combustion of coal is affected by the addition of inorganic compounds.

Submerged Combustion Comes of Age. W. G. See. (Wire and Wire Products, 1940, vol. 15, Feb., pp. 108–110). The author describes the submerged burner equipment and method of control for the heating of pickling baths used by him to obtain the cost data discussed in a previous paper entitled " Submerged Heat by Submerged Combustion." (*See* Journ. I. and S.I., 1940, No. I., p. 153 A).

Waste-Heat Boilers. T. A. Lewis. (Steel, 1940, vol. 106, Mar. 25, pp. 62–64, 79). The author gives some particulars of waste-heat boiler installations at the works of the Bethlehem Steel Co. These utilise the heat from the exhaust of large gas engines. Flue gases enter the boiler at 1200° F. and leave at 350° F. Steam is generated at 165–200 lb. per sq. in. Eight of these boilers were put in during the period 1935–38 and experience has shown that much greater economy is obtained with the gas-engine/waste-heat boiler system than with a turbine power station.

The Technique of Electricity Supply in Foreign Iron and Steel Works. P. Voltz. (Stahl und Eisen, 1940, vol. 60, Apr. 11, pp. 313–321). The author traces the development of the use of electric power in American iron and steel works, and explains why development in that country has followed different paths from that in Germany.

Electricity as Applied to Metallurgy. A. P. M. Fleming. (William Menelaus Memorial Lecture, South Wales Institute of Engineers : Engineering, 1940, vol. 149, Apr. 12, pp. 394–395 ; Apr. 19, p. 421). The author surveys the development of the use of electricity in metallurgy from about 1800, dealing in turn with electrolytic processes, electrothermal processes, welding, electrostatic precipitation, electric power drives and X-ray testing.

The Washing of 0/80 Raw Coal. Cadré. (Revue de l'Industrie Minérale, Mémoires, 1940, Feb., pp. 49–57). The author describes the new coal-washing plant for the treatment of 0–80 mm. coal at the colliery of the Société des Charbonnages de Faulquemont.

The Washing of Coal in a Dense Medium by the Dutch State Mine Loess Process. C. Berthelot. (Revue de l'Industrie Minérale, Mémoires, 1940, Feb., pp. 65–71). The author discusses the principles employed when using a dense medium for washing coal and gives some details of the results achieved by this process at the Dutch State collieries where a suspension of loess in water is used as the medium. (*See* Journ. I. and S.I., 1939, No. II., p. 63 A).

Flocculation as an Aid in the Clarification of Coal Washery Water. H. F. Yancey, R. E. Zane, W. Wood and J. T. H. Cannarella. (United States Bureau of Mines, 1940, Report of Investigations No. 3494). The authors report on an investigation carried out in order to evaluate the effectiveness of various flocculants, both electrolytes and colloids, for settling coal slimes and impurities common in raw coal. They found that starchy materials, such as potato starch and wheat flour are effective flocculants, but they usually show a short range of reagent concentration in which they possess the maximum effectiveness. Electrolytes are effective flocculants over a wider range, but the concentration necessary to produce good flocculation is much higher than with the starchy materials.

Reconstruction of Coking Plant. G. E. Foxwell. (Coke and Smokeless-Fuel Age, 1940, vol. 2, Mar., pp. 65–67). The author presents statistics relating to the coke-producing capacity of coke-oven batteries in Great Britain, showing their age, and discusses the reconstruction policy which he suggests should be followed with regard to plants becoming obsolete.

Some Matters Arising from the Selection, Building and Operating of a New Coking Plant. D. R. Wattleworth. (Year Book of the Coke Oven Managers' Association, 1940, pp. 218–225). The author discusses factors which affect the selection of a design of coke-oven battery from several available types.

Self-Sealing Doors. G. W. Battersby. (Year Book of the Coke Oven Managers' Association, 1940, pp. 146–151). The author describes a number of types of self-sealing doors for coke-ovens and considers their advantages and disadvantages.

The Use of Insulating Concrete in Coke Oven Doors. H. Shaw. (Year Book of the Coke Oven Managers' Association, 1940, pp.

340–346). The author discusses the use of refractory insulating concrete of the china-clay type for lining coke-oven doors and gives some particulars as to costs and the service obtained with it.

Alternative Methods of High Temperature Carbonisation. E. W. Smith. (Year Book of the Coke Oven Managers' Association, 1940, pp. 179–188). The author discusses the differences between the gas and coking industries that justify the great difference in carbonisation plant design and considers the comparative costs of gas production in intermittent vertical chambers, continuous vertical retorts and coke ovens.

Coal Carbonization. D. A. Reynolds and G. W. Birge. (Industrial and Engineering Chemistry, Industrial Edition, 1940, vol. 32, Mar., pp. 363–367). The manner in which gas pressures develop within the uncarbonised part of coal carbonised in cylindrical steel retorts is described. It was found that the pressure increased irregularly as the plastic face moved to the middle of the retort, and it attained a maximum value when the coal at the centre became plastic. The maximum pressures developed when carbonising medium- and low-volatile coals decreased as the carbonising temperature was raised.

The Automatic Control of Coke Ovens and By-Products Plants. L. S. Yoxall. (Year Book of the Coke Oven Managers' Association, 1940, pp. 108–113). In this general discussion of instrumentation on coke-oven plants, the author first describes the principal advantages, disadvantages and characteristics of measuring systems, control systems and controlled valves, and then deals with the application of the different types of instrument at various positions on a plant.

The Reduction of Organic Sulphur Compounds by Oil Washing. C. Cooper. (Year Book of the Coke Oven Managers' Association, 1940, pp. 248–257). The author describes some of the processes for the removal of sulphur from benzol wash oils at gasworks and coke-oven by-product plants.

Operation of Gas Producers. F. J. Matthews. (Foundry Trade Journal, 1940, vol. 62, Mar. 21, pp. 220–222). The author discusses the causes of the inefficient working of gas producers and how the best results may be achieved.

Hydrogenation of a Pittsburgh Seam Coal. H. H. Storch, C. H. Fisher, A. Eisner and L. Clarke. (Industrial and Engineering Chemistry, Industrial Edition, 1940, vol. 32, Mar., pp. 346–353). The authors discuss data obtained during hydrogenation tests at the Bureau of Mines Central Experiment Station on Bruceton coal with special reference to the rates of hydrogen consumption, oxygen removal and liquefaction.

PRODUCTION OF IRON

Three Years' Smelting of German Zinc-Bearing Raw Materials in the Blast-Furnace. H. Klein. (Stahl und Eisen, 1940, vol. 60, Mar. 28, pp. 263–268). The author refers to earlier attempts to recover zinc from the dumps of pyrites residues at Meggen in Westphalia (*see* Journ. I and S.I., 1928, No. I., p. 777), and then describes the experience gained since 1936 in the smelting of these residues in a blast-furnace at Wissen. It has been found possible to work the blast-furnace satisfactorily so as to volatilise the zinc and recover it from the flue dust. It was found necessary to separate the dust rich in zinc from that low in zinc. The addition of common salt to the charge is no longer necessary. The blast-furnace was also worked on a mixture of the pyrites residues (containing about 44% of iron, 8% of zinc, 5% of sulphur and 0·2% of lead) and slag arising from the process of lead production ; this slag contains 25–28% of iron, 11–15% of zinc and about 1·5% of lead, and enormous quantities of it are available. The author also describes experiments undertaken to recover the zinc from the flue dust by electrolysis. In an examination of the costs of the process, he shows that it does not pay, chiefly because of the high coke consumption, but the process has the advantage that it recovers zinc from material which has hitherto been regarded in Germany as waste.

Perin Memorial Lectures. G. B. Waterhouse. (A Pamphlet issued by the Tata Iron and Steel Co., Ltd., Sept., 1939). In this pamphlet nine lectures are reprinted which were delivered by the author at the Tata Iron and Steel Works, Jamshedpur, in commemoration of the services rendered to this company by the late Dr. C. P. Perin. The author deals with the following subjects : (1) General scientific improvements ; (2) blast-furnace practice and pig iron ; (3) foundry practice and cast iron ; (4) basic open-hearth practice ; (5) other steelmaking processes, including the Bessemer, duplex and electric-furnace processes ; (6) rolling mills and heating furnaces ; (7) inspection, specifications and control ; (8) alloy steels ; and (9) modern methods of training metallurgists.

A Historical Note on the Hungarian Iron and Steel Industry. E. Cotel. (Publications of the Department of Mining and Metallurgy, Royal Hungarian Palatine-Joseph University of Technical and Economical Sciences, 1938, vol. 10, No. 3, pp. 425–440). After briefly reviewing the Hungarian iron production in olden times the author deals mainly with the period between the reconciliation with Austria (1867) and the Treaty of Trianon (1920), and he considers, in particular, the influence of some outstanding personalities of this period on the development of the iron and steel industry. In con-

clusion he indicates the losses inflicted on the Hungarian iron and steel industry by the treaty of Trianon and he reports on the latest development of the industry within the new borders, giving information on the yearly production of pig iron and steel between 1921 and 1937.

. . . and President Roosevelt said, Let There Be a Pacific Coast Steel Industry. T. W. Lippert. (Iron Age, 1940, vol. 145, Mar. 21, pp. 25–32). The author examines the proposition that a large steelmaking industry should be established on the Pacific coast of the United States. He comes to the conclusion that the iron ore situation in this area is not attractive and does not indicate the possibility of any large-scale development, that there are no coal resources close to iron ore resources (except in Utah), and that for a number of reasons it would not be economic to establish an industry based on the use of electric furnaces.

FOUNDRY PRACTICE

Ladle Additions for Cast Iron. E. Piwowarsky. (Giesserei, 1940, vol. 27, Apr. 5, pp. 124–125). The author presents a table which forms a convenient survey of the literature and patents since 1900 on the nature and purpose of various ladle additions to molten cast iron.

Enameling Irons. A. S. Hawtin. (Steel, 1940, vol. 106, Mar. 25, pp. 66–67, 76). The author discusses some of the characteristics of cast iron which give rise to enamelling defects, and mentions some precautions to be taken in the cupola and pouring practice in order to prevent the formation of blisters when a casting is enamelled.

Malleable Cast Iron. H. G. Hall. (Institute of British Foundry- men : Foundry Trade Journal, 1940, vol. 62, Mar. 21, pp. 223–228 ; Mar. 28, pp. 237–239). The author explains the mechanism of graphitisation and decarburisation in the preparation of blackheart and whiteheart malleable cast iron respectively. In the second part of his paper he considers the effects of various alloying elements on the properties of malleable cast iron.

The Electric Furnace in the Steel Foundry. F. A. Melmoth. (Electrochemical Society, Apr., 1940, Preprint No. 10). The author compares the technical and economic advantages and disadvantages of acid-lined and basic-lined electric steel furnaces for foundry use.

Molding Sand. W. A. Phair. (Iron Age, 1940, vol. 145, Mar. 7, pp. 48–52). The author describes a moulding sand reclamation plant used by an American foundry for reclaiming cement-bonded silica sand used in the Randupson process of moulding.

Fundamentals of Core Blowing. R. F. Lincoln. (Foundry, 1940, vol. 68, Feb., pp. 23–24, 92–96 ; Mar., pp. 34–36, 94, 97–98). In the first part of his paper the author describes an American type of core-blowing machine and the method of operation. The machine is employed for the rapid production of cores by using compressed air (at 100–120 lb. per sq. in.) to blow the sand into the core box. In the second part he discusses the position and size of the vents through which the air escapes to atmosphere.

Manufacture of Spun-Iron Pipes. S. Spray. (Institute of British Foundrymen : Foundry Trade Journal, 1940, vol. 62, Apr. 25, p. 308). The author describes the centrifugal casting of pipes as practised by the Stanton Iron Co., Ltd., and also gives some particulars of the Mairey process in which a stream of finely powdered ferro-silicon is fed into the revolving mould just ahead of the molten metal. This provides a means of controlling the conditions of cool- ing and prevents the molten metal from being chilled on contact with the mould wall.

Brake Drums Cast Centrifugally. H. H. Fairfield and M. G. Eldred. (Canadian Metals and Metallurgical Industries, 1940, vol. 3, Feb., pp. 31–34). The authors describe the foundry technique for casting large quantities of automobile brake drums. The outer part of the drum is of steel and a special cast-iron lining is centrifugally cast on to it in such a way that the two materials are fused together. To facilitate rapid production a special machine has been developed consisting of ten centrifugal machines mounted on a turntable 18 ft. in dia. Each machine can produce 180 castings per 8-hr. day.

Continuous Casting. E. R. Williams. (Steel, 1940, vol. 106, Apr. 8, pp. 48–49, 56–58, 81). The author describes a method of continuous casting applicable to both ferrous and non-ferrous metal ingots. It was developed in America and its principal feature is the water-cooled mould of high-conductivity material, such as copper, around which the water passes at high velocity. The bottom of the mould is a plate with a number of removable lugs projecting upwards and this plate is attached to mechanism below, capable of drawing it downwards at a speed dependent upon the rate at which the metal enters the mould from a pouring box placed above it. The molten metal solidifies round the lugs in the bottom plate and a means of drawing the ingot down through the mould is thus provided. It is claimed that the mould wall is subject to remarkably little wear, because, after the metal has solidified, it contracts away from the wall. It will be seen that while the ingot is being drawn down through the mould the solid-liquid interface forms an inverted pyramid which remains almost stationary relative to the mould, provided that the pouring rate and the downward movement of the bottom plate are correctly controlled. With this casting system the length of the ingot is limited only by the amount of molten metal available for pouring, for it can be cut in suitable lengths as the solidified metal emerges from the bottom of the mould. In the experimental plant illustrated, a 10-cwt. electric furnace was used, the pouring box was preheated to about 2700° F., the steel was teemed at 150–200° F. above its melting point and, using a 4-in. × 4-in. mould, ingots were drawn through it at about 7 ft. per min. The author states that this system eliminates pipe and that the ingots were remarkably clean as all the impurities rose to the top and passed to the outer surface of the ingot.

Application of Controlled Directional Solidification to Large Steel Castings. J. A. Duma and S. W. Brinson. (Journal of the American Society of Naval Engineers, 1940, vol. 52, Feb., pp. 26–59). The authors describe the moulding technique employed at the steel foundry of the American Navy at Norfolk in order to apply the principle of controlled directional solidification to large steel castings. They give several examples of the successful application of the technique in the manufacture of anchor shanks and heads, large valve bodies, propeller-shaft brackets, turbine casings and heavy ring sections.

PRODUCTION OF STEEL

Andrews Steel Company Diversifies Its Products. T. J. Ess. (Iron and Steel Engineer, 1940, vol. 17, Mar., pp. 29–35). The author describes the plant of the Andrews Steel Co., Newport, Kentucky, a company with a productive capacity of 400,000 tons of ingots per annum, and facilities for rolling blooms, slabs, billets, bars and sheets.

Armco—Pioneer of the Continuous Strip Mill. T. J. Ess and J. D. Kelly. (Iron and Steel Engineer, 1940, vol. 17, Mar., pp. A-1–A-18). A detailed and illustrated description of the Middletown Works, Ohio, of the American Rolling Mill Co. is presented.

Simple Open-Hearth Control. R. Trautschold. (Steel, 1940, vol. 106, Apr. 1, pp. 44, 99). The author gives a brief description of an automatic fuel-control system for use on an open-hearth furnace. It comprises three metering instruments with their respective regulating accessories. The first records the total heat input in B.Th.U. and gives separate records of the air flow and fuel-gas flow ; the second records the gas flow and pressure ; and the third records the furnace draft. This system of instrumentation enables the air supply for combustion to be automatically proportioned to the total heat input.

Deoxidisers Used in Steel Manufacture. (Sheffield Metallurgical Association : Iron and Coal Trades Review, 1940, vol. 140, Apr. 12, p. 571 ; Apr. 19, pp. 611, 613). In a discussion on the effects and efficacy of many deoxidising reagents used in steel manufacture H. Biers emphasised that the silico-manganese treatment offered perhaps the best and most reliable method of establishing an initial level of oxygen content and cleanliness in the bath. R. C. Tucker mentioned he had used calcium-manganese-silicon for deoxidising a 33% chromium cast iron containing 1·5–2% of carbon and had not found much change in the properties of the metal with the exception of a change of fluidity at any given temperature. R. J. Sarjant said that he believed that the ferrous-oxide content of the steel prior to the addition of the deoxidisers was a critical factor in the determination of grain size.

Theory and Practice of Basic Open Hearth Slag Control. F. M. Washburn and W. O. Philbrook. (Iron Age, 1940, vol. 145, Feb. 22, pp. 21–25 ; Feb. 29, pp. 31–35 ; Mar. 7, pp. 58–62 ; Mar. 14, pp. 27–30). After briefly describing the principles of the basic open-hearth process, the authors discuss in turn the mechanism of slag formation, the movement and reactions of the iron oxides, means of measuring the oxidising power of the slag, elimination of carbon, silicon, manganese and phosphorus from the bath, departure from

equilibrium, rates of oxidation of the slag and bath, and the effect of temperature changes. The practice which the authors recommend for controlling the slag in the basic open-hearth furnace may be summarised as follows : (1) To charge a slight deficiency of lime and make additions of burnt lime as necessary to maintain a lime/silica ratio of 2·2–2·5 in the slag ; (2) to maintain a slag with a viscosity of 2–4 in. as measured by the Herty viscosimeter and a lime-silica ratio as in (1) during the refining period by the use of fluorspar ; (3) to charge so that when melted the bath will have a slight excess of carbon and to use hard ore to reduce the carbon rapidly, but not to add ore during the 2 hr. prior to tapping ; and (4) to thicken the slag by the addition of burnt lime just before charging the deoxidisers so as to decrease the rate of transfer of ferrous oxide to the bath.

Preventing the Loss of Manganese in the Open-Hearth Process. P. Bardenheuer and G. Henke. (Stahl und Eisen, 1940, vol. 60, Apr. 25, pp. 353–360). This is an abbreviated version of an article which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 16, pp. 243–260 (*see* Journ. I. and S.I., 1940, No. I., p. 80 A).

A Metallurgical Survey of Machine Cutting Tools. H. W. Pinder. (Alloy Metals Review, 1940, vol. 3, Mar., pp. 7–10). The author discusses factors which govern the casting of a tool-steel ingot, its hot-working and subsequent heat treatment, and the properties of cemented carbide tools.

The Lead-Bearing Steels. L. Guillet. (Revue de Métallurgie, Mémoires, 1940, vol. 37, Feb., pp. 29–36). The author describes the method by which the Inland Steel Co. add lead to molten steel in the preparation of lead-bearing steels by their patented process. He also discusses the chemical, physical and machining properties of this alloy.

Contribution on the Control of Inclusions in Steel Melted in the Basic Open-Hearth Furnace. E. Maurer and G. Voigt. (Stahl und Eisen, 1940, vol. 60, Mar. 21, pp. 241–245 ; Apr. 4, pp. 295–303). The authors, after referring to the literature on methods of reducing the number of inclusions in steel ingots, present data obtained in their own investigation of ingots obtained from eleven melts of axle steel made in a 25-ton basic open-hearth furnace. From these it is apparent that the following conditions must be complied with to produce a plain carbon steel by the scrap carburising process : (1) A high manganese content in the steel prior to deoxidation ; (2) a low content of heavy metal oxides in the slag before teeming ; and (3) a high lime content in the final slag. The same conditions apply when working with pig iron and scrap. When producing chromium steel (chromium up to 0·80%) only the first of the above conditions has to be met.

ROLLING-MILL PRACTICE

Rolls—The Past—Present—and Future. R. P. Perry. (Iron and Steel, 1940, vol. 13, Mar., pp. 175–179). The author describes the casting of rolls and their maintenance in sheet-mill practice, with particular reference to the importance of temperature control during warming-up and during rolling. He concludes his paper with a discussion of the measurement of the concavity of roll surfaces.

The Importance of Salvaging and Saving Industrial Lubricants in War-time. L. D. Colam. (Iron and Steel, 1940, vol. 13, Mar., pp. 187–190). The author states that, generally speaking, a good oil when reclaimed will have properties equal to, if not better than, those it had originally because a regenerated oil is free from those substances which crack most easily under high temperatures and is also much more free from the unsaturated hydrocarbons which, by reason of oxidation, form sludge. He then discusses the classification of impurities in oils, and describes some methods of reclaiming oils and of economising in the consumption of grease for lubricating rolling-mill machinery.

New Slabber-Edger Setup. (Steel, 1940, vol. 106, Mar. 18, pp. 48–49, 76–77, 84). Some recent improvements to the rolling mills of the American Rolling Mill Co., Middletown, Ohio, are described. These include the installation of a 72-in. reversing slabbing mill and a separate " edging" unit. A special feature of the control equipment for the mill motors is the automatic adjustment of the excitation.

Continuous Steel Strip Manufacture. J. Zeelander. (Mechanical World, 1940, vol. 107, Feb. 23, pp. 166–167 ; Mar. 29, pp. 277–278). The author presents two flow sheets with descriptive data which together form a comprehensive picture of all the processes involved from the preparation of coal and ore to the production of finished continuously rolled steel strip.

The Manufacture of Seamless Ferrous Tubes. C. Billingsley. (Proceedings of the Institution of Mechanical Engineers, 1940, vol. 143, Apr., pp. 61–72). The author describes the methods and machines used for the production of seamless steel tubes by the Mannesmann, Stiefel and Wellman processes.

Butt Welding Pipe Continuously. J. Hopkins and T. C. Campbell. (Iron Age, 1940, vol. 145, Mar. 28, pp. 35–39). The authors describe the Fretz-Moon process of making steel tubes and survey its development in the United States.

HEAT TREATMENT

Some Factors Affecting Carburization. T. A. Frischman. (Heat Treating and Forging, 1940, vol. 26, Feb., pp. 65–67). The author describes some experiments which illustrate the effect of changes in the particle size of carburising compounds on the degree of carburisation produced at different depths in a number of carbon and low-alloy steels.

The Hardenability of Carburising Steels. W. H. Bruckner. (Illinois University, 1939, Engineering Experiment Station Bulletin Series No. 320). It had been observed that in applying the hardenability test of Jominy and Boegehold (*see* Journ. I. and S.I., 1938, No. I., p. 69 A) to a series of S.A.E. steels of apparently the same chemical composition and grain size different results were attained. In the present investigation the author examined the hardenability of nine different steels of analyses within the following limits: Carbon 0·10–0·20%, chromium 0·10–1·57%, nickel 0·14–3·53% and molybdenum 0·01–0·24%, in order to ascertain whether the above test was valid for these low-alloy steels. The author's general conclusions are: (1) The hardenability is greater the higher the alloy content of the steel; (2) in the S.A.E. 4615–4620 grade of steel higher hardenability is more often obtained when the total alloy content is above 2·90% and the chromium above 0·17%; (3) the fact that steels of the same composition and grain size and with the same amount of inclusions do not harden to the same extent when carburised is apparently due to the difference in the distribution of the inclusions.

Induction Method of Surface Hardening. H. B. Osborn, jun. (Industrial Heating, 1940, vol. 7, Jan., pp. 26–32; Feb., pp. 107–112). After explaining the principles of heating by induction with high-frequency electric currents, the author describes and illustrates apparatus for applying this form of heating to steel for surface-hardening purposes. In discussing the transformation and the final structure obtained by this process the author shows that although a considerable amount of free ferrite might be anticipated in view of the extremely rapid transformation from pearlite to austenite and the tendency of this transformation to occur between the lower and upper critical temperatures, this does not take place in practice as the major portion of the ferrite persists until most of the carbides have been diffused; the final stage of the process is the removal of free ferrite and the formation of a fine homogeneous structure which is retained on quenching. In the second part of this article the author presents a table of analyses of steels which have been successfully hardened by the induction process, and describes and illustrates some hardening units available for treating automobile crankshafts and camshafts.

How to Anneal for Superior Drawing Qualities. J. N. Crombie. (Steel, 1940, vol. 106, Mar. 18, pp. 44–47). The author describes some experiments designed to show the influence of the temperature of short-time annealing on the grain size and drawing quality of 0.06% carbon steel sheet for porcelain enamelling. Blanks $20\frac{1}{2}$ in. in dia. $\times$ 0.024 in. thick were cold-drawn in four stages into cups 8 in. in dia. $\times$ $9\frac{1}{4}$ in. deep ; 1-in. squares were scribed on the blanks and from these the percentage elongation at various positions along the cup was measured. Test strips were cut parallel with the axis of the cup and these were annealed separately for 2 min. at temperatures between $1000°$ and $1700°$ F. and the grain size at various percentages of elongation was determined. The results are shown by curves in which the grain size is plotted against the annealing temperature. These curves show that for elongations of 5%, 7.5% and 10% the grain growth is much larger than when the elongation is 15% or more, regardless of the annealing temperature, provided that this is below the A_3 point of the steel in question.

Annealing of Tool Steels. I. Golikov. (Iron and Steel, 1940, vol. 13, Apr., pp. 241–244). This is an abridged English translation of an article which appeared in Stal, 1939, No. 6, pp. 32–39. The author considers first whether a lamellar or a granular pearlite structure in tool steel is the best to meet the consumer's needs and states that one should aim at obtaining a structure of uniform granular carbide as a result of the annealing treatment. In discussing the selection of the optimum maximum temperature for annealing, the author shows that there is a definite range of annealing temperatures the use of which leads to the formation of granular pearlite. For any given steel the lower temperature of this range is the temperature at which the transformation at Ac_1 is complete, while the upper temperature of the range is that at which the first regions of lamellar pearlite again make their appearance in the annealed steel. The time during which the steel is held at the maximum annealing temperature has much less influence on the structure than the temperature itself. In conclusion, the author points out that in choosing annealing schedules for tool steels conditions existing in the furnace to be used must be taken into account ; for example, allowance must be made for the difference in the heating and cooling rates of the inside and outside portions of a large batch of stock.

The Influence of Controlled Atmospheres in the Heat Treatment of Steel. A. Fisher. (Machinery, 1940, vol. 56, Apr. 11, pp. 51–56). The author discusses from the point of view of heat treatment the type of atmosphere produced by the partial combustion of a fuel with particular reference to town and producer gas. He presents charts showing the atmosphere analyses to be expected with varying air/gas ratios using each type of fuel.

A Note on the Mechanism of Blister Formation in the Scaling of Metals. W. Baukloh and G. Thiel. (Korrosion und Metallschutz,

1940, vol. 16, Apr., pp. 121–126). The effect of pickling is better if the scale is homogeneous and free from blisters. The authors therefore studied the causes of the formation of blisters in the scaling of iron. In contrast to Griffiths (*see* Journ. I. and S.I., 1934, No. II., p. 377 A and 1935, No. II., p. 67 A) they found that the presence of an inert gas is not necessarily the condition for blister formation during scaling, as this may also be due to the presence of all kinds of oxidising gases. They watched the formation of blisters during the scaling of specimens which, in the presence of various gases, were electrically heated in gas-tight transparent quartz tubes. They compared the behaviour of copper and iron specimens when heated in air, the scale on the former always being free from blisters. They came to the conclusion that blister formation is only possible if the value of γ is high, *i.e.*, the ratio of the specific volume of the scale to that of the metal. The value of γ is about 2 for iron and about 1·3 for copper.

Stress-Relieved Cast Irons. A. Le Thomas. (Foundry Trade Journal, 1940, vol. 62, Mar. 21, pp. 217–218, 232). The author describes some experiments which illustrate the magnitude of the internal stresses which occur in certain shapes of iron castings on cooling and gives the French Admiralty Specification for heat treatment to relieve such stresses. This treatment consists of holding the casting at about 500° C. for 24–48 hr. and cooling very slowly.

A Note on the Absorption of Graphite in Hardening and Tempering Cast Iron. J. E. Hurst. (Metallurgia, 1940, vol. 21, Feb., pp. 91–94). The author studied the relation between the hardness and chemical composition of a number of ordinary and alloy cast irons in the as-cast, annealed, quenched and tempered states. The results clearly indicate an influence of the percentage of combined carbon on the hardness, the hardening effect, as with steel, being due to the formation of a martensitic structure. The author briefly considers the conditions for the absorption of graphitic carbon in hardening and tempering operations, in particular with regard to the influence of the temperature and of the original composition of the cast iron. Of especial interest are data which he gives showing that quench-hardening also causes absorption of graphite in qualities of cast iron which prior to this treatment do not contain any combined carbon.

Developing Special Properties by Heat Treating the Malleable Irons. R. J. Cowan. (Transactions of the American Foundrymen's Association, 1940, vol. 48, Dec., pp. 283–292 : Steel, 1940, vol. 106, Mar. 25, pp. 44–47, 72, 80). The author describes the structure of malleable cast iron with the aid of several micrographs, and explains how heat treatment can be applied to change the size and distribution of the graphitic carbon in the structure.

WELDING AND CUTTING

Process Control of Spot Welding. C. L. Hibert. (Iron Age, 1940, vol. 145, Mar. 7, pp. 43–47 ; Mar. 14, pp. 31–34). The author refers to some recent improvements in spot-welding technique and describes how satisfactory welds are obtained by control of (a) the duration of the current, (b) the shape of the electrodes, (c) the pressure on the electrodes, (d) the contact resistance, and (e) the current density, as well as by proper attention to equipment, training and supervision of personnel, design and inspection.

Determination of Electrode Quantities and Numbers with the Aid of a Nomogram. M. Renger. (Electroschweissung, 1940, vol. 11, Mar., pp. 41–44). The author presents a nomogram which facilitates the calculation of the weight and number of electrodes required for electric welding when such factors as the thickness of weld, angle of groove and diameter of electrode are known.

On the Welding of Plated Sheets. G. Richter. (Metallwirtschaft, 1940, vol. 19, Apr. 10, pp. 267–276). The author discusses the results obtained in an investigation of the strength and corrosion resistance of butt-welded joints in sheets plated with copper, nickel, *V2A* alloy, Remanit 1880*S*, silver and Sicromal (*see* Journ. I. and S.I., 1939, No. II., p. 26 A).

The Welding of Light Tubular Structures of Chromium-Molybdenum Steel. A. Boutté. (Revue de la Soudure Autogène, 1940, vol. 32, Feb., pp. 836–837). The author describes the correct technique to follow and the precautions to be taken in the oxyacetylene welding of joints in chromium-molybdenum steel tubes. It is very important that the acetylene should be as pure as possible, and, as a means of testing this, the author suggests using a filter paper soaked with a few drops of silver nitrate solution. If a gentle stream of the acetylene is allowed to impinge on the filter paper, the soaked portion should remain white, or at most, turn a slight grey colour ; if the paper turns black then the acetylene should not be used, as it contains hydrogen phosphide.

Tubes Electrically Welded. J. B. Borgat. (Steel, 1940, vol. 106, Mar. 11, pp. 52–54, 79–80). The author describes a method of manufacturing steel tubes by electric welding in a machine the novel feature of which is that instead of roller electrodes being employed, flat contactors of a copper alloy, silver-plated on the contact surface, are used. It is claimed that the grain size of the welded joint can be controlled by adjusting the mechanical pressure, and the time and strength of the current.

Examination of Welded-Steel Specimens from the Hasselt Bridge. L. Reeve. (Transactions of the Institute of Welding, 1940, vol. 3.

Jan., pp. 3–13). This is the report of the R.11 Sub-Committee on the Weldability of High Tensile Structural Steels appointed by the Welding Research Council of the Institute of Welding recording their examination of several specimens of steel and attached welds from the broken Hasselt Bridge in Belgium.

Welding Practice in Relation to Coke Oven and Gasworks Plant. H. H. Hollis. (Year Book of the Coke Oven Managers' Association, 1940, pp. 328–336). The author describes the construction of arc-welded gasholders, purifiers, and tanks as well as repairs by welding to miscellaneous plant at gasworks and coke-ovens.

Austenitic Grain Size of Covered Electrode Deposits. H. Granberry. (Welding Journal, 1940, vol. 19, Mar., pp. 98-S–99-S). The author reports on an investigation undertaken to ascertain the influence of different types of welding electrode coatings on the grain size of the deposited metal. Three types of coating were tested ; one produced a high percentage of gas to shield the arc, the second was high in titanium oxide and the third was high in iron oxide. There was no wide variation in the grain size of the welds, but it was observed that the electrodes with the coating high in titanium oxide tended to produce a smaller grain size in the weld than either of the others.

Welding as a Substitute for Casting. S. F. Dorey. (Transactions of the Institution of Engineers and Shipbuilders in Scotland, 1940, pp. 168–189). The author indicates the progress that has been made in the substitution of welded mild steel parts for ferrous castings. He claims certain advantages for welded structures over castings. He deals with the main factors on which the production of sound and efficient welded structures depends, and describes and illustrates typical examples of such structures used in different branches of engineering.

The Causes of the Burning-Out of Oxygen-Reducing Valves and Means of Preventing This. W. Rimarski and K. Noack. (Autogene Metallbearbeitung, 1940, vol. 33, Mar. 15, pp. 69–76 ; Apr. 1, pp. 86–90). The authors examine the causes of spontaneous ignition and burning of the valves and packing in oxygen pressure regulators used for oxy-acetylene welding and cutting.

Underwater Cutting, Arc Cutting, the Oxygen Lance, and Oxygen Deseaming and Machining. W. Spraragen and G. E. Claussen. (Welding Journal, 1940, vol. 19, Mar., pp. 81-S–96-S). The authors review the literature to Jan. 1, 1939, on the apparatus and technique for cutting and welding steel under water, cutting steel with an electric arc from carbon or from metal electrodes, cutting thick steel and cast iron with the oxygen lance, deseaming or the removal of cracks and defects from billets and ingots with an oxygen jet after preheating, and for cutting profiles with an oxy-acetylene cutting machine.

MACHINING

Cast Iron and Its Relation to Machine Tools. P. A. Russell. (Institute of British Foundrymen : Foundry Trade Journal, 1940, vol. 62, Mar. 14, pp. 205–207). In the first part of this paper the author considers the properties of ordinary and special quality cast irons and their application in the manufacture of machine tools, and in the second part he deals with their machining properties. He describes Beeny's drill-penetration test by which the machinability of an iron is measured by the depth of penetration of a tungsten-carbide-tipped drill, $\frac{1}{2}$ in. in dia., under a load of 51 lb. after 100 revolutions, and he presents curves in which this penetration is plotted against the tensile strength and the Brinell hardness of a number of cast irons ; these curves show that neither the tensile strength nor the hardness is a true guide to the machinability.

Properties and Machinability of a Leaded Steel. T. J. Dolan and B. R. Price. (Metals and Alloys, 1940, vol. 11, Jan., pp. 20–27). The authors present and discuss the results of tests on the mechanical properties, hardenability, grain size and machinability of a variety of steels containing 0.20% of lead. Their general conclusion is that whilst leaded steel has a higher initial cost than ordinary steel its technical value is about the same as that of the same steel without the lead, except with regard to machinability, where the leaded steel offers definite advantages which can be used to reduce process costs and to speed up production. In estimating the reduction in costs, allowance must be made for any additional equipment required to deal with the danger of lead fumes in welding and oxy-acetylene cutting operations.

Machining Stainless Steel. C. W. Aleschand and G. J. Stevens. (Iron Age, 1940, vol. 145, Jan. 25, pp. 23–29). The authors describe a number of machining tests on stainless steel and discuss the results obtained. The tests indicate the influence of the composition and processing on the life of lathe tools, drills and reamers and offer valuable general information to the machine operators.

Selection of High-Speed Steel. P. Orlets. (Stal, 1939, No. 4–5, pp. 60–63). (In Russian). The author discusses the connection between the composition and cutting properties of the 18/4/1 tungsten-chromium-vanadium types of high-speed steels and considers the possible changes in the composition of standard Russian steels of this type, from the point of view both of cutting properties and of economy of alloying constituents.

CLEANING AND PICKLING OF METALS

Metal Cleaning by Sand Blasting, Tumbling, Rolling and Burnishing. C. C. Hermann and R. W. Mitchell. (Iron Age, 1940, vol. 145, Mar. 7, pp. 54–57). The authors describe some of the plant and machines used at American foundries for cleaning castings by sandblasting, shot-blasting, tumbling, rolling and burnishing.

Flame Descaling, Cleaning, Dehydrating. J. G. Magrath. (Steel, 1940, vol. 106, Apr. 1, pp. 54–56). The author describes a " brush " form of oxy-acetylene torch for the descaling of billets, bars and plates. A detailed description of this appliance has been published previously (*see* Journ. I. and S.I., 1940, No. I., p. 153 A).

Mechanical Billet Chipping. G. W. Lentz. (Iron and Steel Engineer, 1940, vol. 17, Mar., pp. 26–28). The author describes a billet-chipping machine and presents data relating to its performance and power consumption. The machine carries a travelling revolving head in which eight cutting tools are clamped. The head revolves at 8 r.p.m. so that 64 cuts per min. can be made. When cleaning the entire surface of a billet with no bad defects, 250 sq. in. per min. can be cleaned.

Preparation of Semi-Finished Steel. A. P. Spooner. (Iron and Steel Engineer, 1940, vol. 17, Mar., pp. 22–25). The author discusses the removal of surface defects from ingots and billets and compares the costs of double heating, double converting, pneumatic hammer chipping, mechanical chipping, scarfing and grinding. In double heating the semi-rolled bloom is partially or fully cooled, then reheated and rolled to size, whilst in double conversion the surface is conditioned by scarfing or chipping before heating.

Surface Films in Metal Industry. E. C. Rinker. (Metal Industry, New York, 1940, vol. 38, Jan., pp. 20–21). The author discusses the technique of rinsing for the removal of films arising from (*a*) mineral oils and greases and (*b*) soaps and fatty acids from metal sheets.

Taking the Stain off Stainless. G. C. Kiefer. (Machinist, 1940, vol. 84, Mar. 30, pp. 50–52). After referring to some of the ways in which the surface of stainless steel may be contaminated, *e.g.*, by iron particles from tools, lubricants, fluxes or solder containing lead, the author makes recommendations as to the composition of rinsing and pickling solutions which will prevent defects from appearing in the finished article.

COATING OF METALS

The Theory of the Potential and the Technical Practice of Electro-deposition. C. Kasper. (Electrochemical Society, Apr., 1940, Preprint No. 23). The present paper is the first of a series on those aspects of the theory of electricity which are of importance in the practice of electrodeposition ; in it the author explains the theory of conductivity.

Glycerine in Metal Processing. Georgia Leffingwell and M. A. Lesser. (Metal Industry, New York, 1940, vol. 38, Feb., pp. 79–81). The authors present a brief survey of the literature and patents covering the use of glycerine in metal processing. It is an important ingredient of plating solutions, quenching media and fluxes for galvanising and soldering.

Chromium Plating of Motor Cylinders. H. Van der Horst. (Metal Industry, New York, 1940, vol. 38, Feb., pp. 76–78). The author gives a brief description of an electrolytic chromium-plating process in use at Hilversum, Holland, by which large marine engine cylinder castings are given a porous coating of chromium. The advantages of this coating are that it holds oil and that it can easily be honed. It is claimed that the life of cylinders which have been plated by this process is very greatly increased.

The Present State of Cladding in Chemical Plant Construction. W. Rädeker. (Metallwirtschaft, 1940, vol. 19, Apr. 10, pp. 279–283). The author reviews the metals and alloys suitable for use as base metals and metal coatings, and he discusses the conditions for good adhesion of the cladding material. He considers very briefly the methods of hot- and cold-working and of testing composite materials, and points out that the chemical resistance of clad metal is the same as that of the surface material, provided that the latter is not porous and is free from defects. In conclusion he gives some information concerning the welding of composite materials and the examination of the welds obtained.

Mecano-Bundy, the Copper-Plated Steel Tube Made by the Bundy Process. H. Sickinger. (Metallwirtschaft, 1940, vol. 19, Apr. 10, pp. 277–279). Mecano-Bundy tubes are copper-plated steel tubes with an outside diameter of 3 to 10 mm., the wall thickness being 0·7 to 0·8 mm., and 2 mm. for special applications. The tubes are used in place of copper and seamless steel tubes and are said to combine the advantages of both. The Mecano-Bundy tube is a further development of the Bundy tube, the latter having been produced in great quantities in the United States since 1931. As raw material for Mecano-Bundy tubes low-carbon steel strips are used which, after cold-rolling, are copper-plated on both sides,

the coatings being about 0·004 mm. thick. Then the strips are subjected to further mechanical treatment, and the tubes formed in such a way that their walls are built up of two layers of the strip. The walls are thus not only coated with copper but have also an internal copper layer. Finally the tubes are subjected to a special heat treatment causing the formation of a eutectic alloy in the boundary layers between the copper and steel. In conclusion the author gives some data concerning the metallographic structure of the tubes, their mechanical properties and their corrosion resistance.

Composite Tubes. H. Philippi. (Metallwirtschaft, 1940, vol. 19, Apr. 10, pp. 276–277). The author briefly reviews the methods of production, the properties and applications of composite tubes, referring in particular to soft-iron and alloy-steel tubes clad with copper or copper alloys.

Develops Improved Process for Integrally Bonding Steels of Different Compositions. H. G. Batchellor. (Heat Treating and Forging, 1940, vol. 26, Feb., pp. 68–71). The author's article on the production of ingots and plate of composite steel by the " Pluramelt " process is reproduced. (*See* Journ. I. and S.I., 1940, No. I., p. 282 A).

Plural Compositions from a New Melting Process. V. Browne and H. Blumberg. (Metal Progress, 1940, vol. 37, Feb., pp. 163–168). The authors present data on the properties of composite steel made by the " Pluramelt " process and discuss its possible applications.

Gas-Fired Galvanising Equipment. F. M. Carlson. (Metal Industry, New York, 1939, vol. 37, Dec., pp. 577–579). The author describes an improved design of galvanising kettle installed at an American works where about 18 tons of material per week are galvanised. The kettle is 7 ft. long, 32 in. deep and 28 in. across the top. It is heated with a mixture of natural gas and coke-oven gas passing through flues of unusual design which effect important economies. The waste gases are also utilised to heat drying tables.

The Hot Galvanizing of Wire. (Metallurgia, 1940, vol. 21, Jan., pp. 77–80 ; Feb., pp. 127–128). After briefly discussing the theory of corrosion and old methods of galvanising wire, a full description is given of the modern hot-bath technique for depositing thin and heavy zinc coatings on steel wire.

Tin Plate in the Canning Industry. B. W. Gonser. (Metal Progress, 1940, vol. 37, Feb., pp. 135–141, 196). A general account is given of the process of manufacturing tinplate and of the mass production of tin cans. The account is based on information published by the International Tin Research and Development Council.

The Electrolytic Manufacture of Tinplate Strip. C. C. Downie. (Blast Furnace and Steel Plant, 1940, vol. 28, Feb., pp. 183–184, 186). The author's review of some modern methods for the electrodeposition of tin on steel strip is reproduced (*see* Journ. I. and S.I., 1940, No. I., p. 248 A).

Hot-Dip Tinning of Milk Cans and Ice Cream Cans. W. G. Imhoff. (Metal Industry, New York, 1939, vol. 37, Dec., pp. 573–576). The author describes the raw materials, equipment and technique employed for the tinning of milk cans in accordance with American practice.

Protective Films on Iron from the Vapour of Silico-Organic Compounds. I. D. Yudin. (Comptes Rendus de l'Académie des Sciences de l'U.R.S.S., 1939, vol. 25, No. 7, pp. 614–617). The author reports on a study of the corrosion-resistance properties imparted to steel by heating for 15–20 min. at 280–300° C. in the presence of silico-organic compounds of the type $Si(OR)_4$ where " R " is an alkyl radical. It was found that the film produced on the specimens by the vapour from tetra-ethyl-silicon offered a high resistance to attack by 3% sodium chloride solution.

Rust Proofing and Finishing of Unit Heater Casings and Convector Enclosures. C. T. Perkins. (Metal Industry, New York, 1939, vol. 37, Dec., pp. 602–604). The author describes the bonderising plant at an American works manufacturing convection heating units. The process is a continuous one, and the sheet-metal panels which are to form the casing of the heater are carried on the hooks of a trolley conveyor through a tunnel divided into a series of chambers in which the operations of washing, drying, spraying, baking and cooling take place.

Protecting Metals by Organic Coatings. O. J. Schierholz. (Canadian Metals and Metallurgical Industries, 1940, vol. 3, Jan., pp. 1–5, 11). After enumerating nine possible causes of paint-film failure the author deals, in an elementary way, with the electro-chemical theory of corrosion, applying it also to iron protected by various paint films. He also discusses various measures for curbing corrosion by the suitable choice and application of paint films. He emphasises the importance of the good adhesion of protective films, and briefly reviews the technical methods of applying them. He then discusses the most important pigments and vehicles used for modern protective paints, giving particular consideration to the dispersion of the pigment and to the ratio of pigment to vehicle. Finally, he enumerates some new types of protective coatings which he thinks likely to become of practical importance soon.

Phosphorus Steels for Vitreous Enamelling. C. H. Lorig and D. E. Krause. (Journal of the American Ceramic Society, 1940, vol. 23, Apr., pp. 107–110). The authors report on some tests undertaken with the object of ascertaining the effect of variations in the phosphorus content of steel sheet on its enamelling properties. One series of tests was made with enamelled strips 10 in. × 4 in., of 22 gauge sheet containing from 0·005% to 0·40% of phosphorus ; these were placed on supports $8\frac{1}{2}$ in. apart and the amount of sag after firing was measured. The results showed that the amount of sag decreased with increasing phosphorus content ; in fact, the specimen containing 0·40% of phosphorus arched upwards. Other

conclusions arrived at by these experiments were : (1) Killed steel has more sag-resistance than rimmed steel ; (2) from an enamelling standpoint, it is more desirable to gain strength in the sheet by increasing the phosphorus than by increasing the carbon ; (3) the A_3 point of enamelling iron is raised by increasing the phosphorus content ; (4) changes in the phosphorus content do not appear to affect the occurrence of common enamelling defects ; (5) up to 0·40% of phosphorus in flat sheet has no marked effect on the adherence properties, but a higher content reduces the adherence ; and (6) increasing the phosphorus content reduces the drawing properties of steel sheet.

De-Enamelling of Vitreous Enamelled Steel and Sheet Iron. N. L. Evans. (Foundry Trade Journal, 1940, vol. 62, Feb. 1, pp. 102–103 ; Mar. 7, pp. 188–189). The author describes two processes for de-enamelling sheet steel articles which have been made by expensive pressing operations and have been rejected owing to enamelling defects. The first process consists of soaking in a 50% caustic soda solution maintained at a temperature just under boiling point, with subsequent rinsing, brushing and neutralising treatments. The time taken by this process is usually about 12 hr. The second method requires more elaborate and costly plant, but the time required is only 5 min. The article is soaked in molten caustic soda at a temperature of 500–600° C., is dipped in 10% hydrochloric acid, then in clean water and finally it is given a neutralising rinse in soda solution. The author also gives in- formation on the disposal of sludge from the plant, safety precautions and the treatment of caustic burns.

Rust-Preventing Paint in Connection with Raw-Material Economy. H. F. Sarx. (Korrosion und Metallschutz, 1940, vol. 16, Mar., pp. 77–81). After emphasising the importance of suitable technique for applying paint and of immediately repairing defects in the coating, the author discusses the development in recent years of anti-corrosive paints dealing in particular with synthetic resin and chlorinated rubber base paints. He indicates briefly the suitability of these paints for various purposes, referring to experience gained by the German State Railways, the German navy, air force and postal authorities, and by a number of important firms.

PROPERTIES AND TESTS

Interpretation of Test Results. O. W. McMullan. (Iron Age, 1940, vol. 145, Mar. 14, pp. 23–26; Mar. 21, pp. 40–44). The author discusses the purpose and practical value of the results obtained by mechanical tests on steel, dealing in turn with the characteristics revealed by etching and by tensile, impact, hardness, wear-resistance, torsion, bend, shear, compression and cupping tests.

Materials the Elastic Moduli of which have a Special Relationship to the Temperature. H. Fahlenbrach and H. H. Meyer. (Technische Mitteilungen Krupp, Technische Berichte, 1940, vol. 8, Apr., pp. 25–28). The authors report on the development of some special steels of which the temperature coefficient of the elastic modulus is extraordinarily small. They deal in particular with the alloys $WT11$ and $WT8$, which are special nickel-chromium and nickel-chromium-molybdenum steels, the compositions of which are not given. The temperature coefficient of the elastic modulus of $WT11$ can be made approximately zero by a special heat treatment. $WT11$ is thus particularly suitable as a material for tuning forks. It is not sufficiently hard however to allow of its use as a material for springs. For this purpose the alloy $WT8$ has been developed, of which the temperature coefficient of the elastic modulus is $+ 25 \times 10^{-6}$ with a Brinell hardness of 250–300.

Contribution on the Tensile Strength of Cast Iron in Relation to Temperature. F. Roll. (Giesserei, 1940, vol. 27, Apr. 5, pp. 123–124). The author discusses the results obtained in an investigation of the changes in tensile strength with rising temperature of two pearlitic cast irons. The results are given in tables and graphs, and these show that as the temperature rises the tensile strength decreases at a steadily increasing rate until the A_1–A_3 range is reached. In this region there is a marked irregularity in the readings and above it the tensile strength decreases at first very rapidly and then more slowly.

Non-Uniform Yielding in Metals during a Tensile Test. Constance Elam. (Engineering, 1940, vol. 149, Mar. 29, pp. 325–327). A description is given of some tensile tests on Armco iron, steel and aluminium alloys using a special apparatus with which accurate load and extension curves in relation to time could be plotted; this enabled data to be obtained regarding the "jumps" in which extension took place in the plastic range. It is considered probable that all deformation is a discontinuous process, but that in most cases the steps are too small to be detected in an ordinary testing machine. It is stated that the first cause of the non-uniform yielding lies in the inherent properties of the material as a result of

which the stress required to initiate plastic deformation is greater than that required to maintain it.

Is it Possible to Replace the 0·2% Proof Stress by a Non-Arbitrary Yield Point? H. Esser and H. Arend. (Archiv für das Eisenhütten-wesen, 1940, vol. 13, Apr., pp. 425–428). For materials having no clear yield point it is usual to determine the stress causing a perman-ent elongation of 0·2%. The authors point out that this 0·2% proof stress is an arbitrary criterion having no true relation to the yield point. They suggest the plotting of stress-elongation diagrams on logarithmic graph paper. The stress-elongation curves traced on this paper always show a distinct point of inflection, and the authors suggest the use of this point as an indication of the yield point. Curves clearly showing the points of inflection are reproduced for six qualities of steel and a number of non-ferrous metals.

Recent Development of Steel St 52 for Large Structural Work. E. H. Schulz and W. Bischof. (Zeitschrift des Vereines deutscher Ingenieure, 1940, vol. 84, Apr. 6, pp. 229–235). The authors discuss the development of steel St 52 in Germany and the reasons which led to the establishment of the bend test on weld metal (*see* Journ. I. and S.I., 1940, No. I., p. 244 A).

A Study of Hot Torsional Deformations. J. Galibourg and L. Guillet. (Revue de Métallurgie, Mémoires, 1940, vol. 37, Jan., pp. 1–15). The authors first describe a torsional testing apparatus in-corporating an electric furnace with which they carried out tests on steel specimens turned to 9·77 mm. in dia. on a length of 10 cm. The steels tested included a mild carbon steel, two chromium-molyb-denum steels and one austenitic stainless steel. The amount of torsion under varying loads was measured at temperatures up to 550° C. and the results are shown in numerous tables and graphs.

Stress Measurement by Magnetostriction. F. D. Smith and C. A. Luxford. (Proceedings of the Institution of Mechanical Engineers, 1940, vol. 143, Apr., pp. 56–59). After referring to the changes in the magnetic permeability of a ferromagnetic material which is mechanically stressed, the authors show how this pheno-menon can be used to study transient mechanical stresses. The stress is applied by suitable mechanism to the ferromagnetic core of a transformer or coil, and the resulting magnetic changes in the core are observed by the help of appropriate electrical circuits on the screen of a cathode ray oscillograph. The authors set out the condi-tions to be observed for the successful use of such apparatus and give data as a guide to the design of magnetostriction stress-measuring devices.

The Calculation of the Internal Stresses in Large Hardened Hollow Machinery-Steel Cylinders. H. Treppschuh. (Archiv für das Eisen-hüttenwesen, 1940, vol. 13, Apr., pp. 429–436). The distribution and values of the internal stresses of hollow chromium steel rolls for cold-rolling with outside diameters of 385 and 250 mm. are calculated in one case when the rolls have been quenched by a water spray on

the outside only, and in a second case when they were quenched on both the inside and outside.

British Standard Method for Direct Reading Hardness Testing (Rockwell Principle). (British Standards Institution, No. 891–1940). In the hardness test described in this British Standard Specification a minor load is first applied to a penetrator and, while this still operates, it is augmented by a major load with resulting increase in the depth of indentation. The Rockwell hardness numbers are read directly on an indicator and are derived from measurements of the depths of the two impressions.

Methods of Hardness Testing and Their Sources of Error. H. von Weingraber. (Metallwirtschaft, 1940, vol. 19, Mar. 29, pp. 255–260). In this mathematical discussion the author considers and compares the characteristics of the various methods of hardness testing and their sources of error. He is of the opinion that the pyramid hardness numbers should be adopted as standard hardness units because of the accuracy of the determinations and because this method of testing covers the full hardness range.

Falling-Pendulum Hardness Testing Machines. H. Cornelius and W. Trossen. (Stahl und Eisen, 1940, vol. 60, Apr. 4, pp. 293–294). The authors describe a new form of falling-pendulum hardness tester which is fitted with an electric heater so arranged that the specimen can be tested in several different places without having to remove it from the heater. They present the results of hardness tests at temperatures from 900° to 20° C. on a number of steel and non-ferrous-metal specimens.

The Mechanism of Wear. T. U. Matthew. (Journal of the South African Institution of Engineers, 1940, vol. 38, Feb., pp. 229–250). The author deals briefly with the main results of scientific research on the wear of polished surfaces and relates recent developments in the technique of wear-resistance to the new knowledge of the wear process. He describes and illustrates an apparatus in which one polished metal specimen was moved over another one under a constant load; with the aid of an oscillograph and a cinema camera, a record of the changes in frictional force was obtained on a scale of 1 in. of film for a movement of 0·012 in. of the specimen. The record of the movement of one polished mild steel surface upon another thus obtained showed a remarkably consistent series of seizures followed by shear. It was observed that there was a very close resemblance between the stress-strain diagrams for mild steel when strained very slowly, and the minute stress-strain diagrams obtained at each seize-shear jump. From numerous experiments made with the above apparatus the author concludes that friction and wear between surfaces in sliding contact is the result of seizure followed by shear, and that seizure is due to molecular cohesion. In general, the more plastic metals seize most readily on themselves and on similar single-phase metals, whilst hard metals and complex structures of hard and soft components are much

more resistant to seizure on themselves or on other metals. In the concluding portion of the paper the author discusses methods of determining the wear-resistance of metals and he shows how wear-resistance technique has been developed in regard to : (a) the wear of cutting edges ; (b) the wear of materials subject to high temperatures and oxidising conditions ; (c) the wear of materials subject to high impact-loading conditions ; and (d) the wear of lubricated bearing surfaces. (An extended abstract of this paper appeared in Foundry Trade Journal, 1940, vol. 62, Apr. 25, p. 307).

On the Mechanism of the Abrasion of Metals. M. Kuroda. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Nov., pp. 185–189). (In Japanese). The author proposes a system of nomenclature and classification of the different kinds of abrasion.

The Mechanism of Abrasion Discussed from the Crystallographical Point of View. M. Masima. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Nov., pp. 97–104). (In Japanese). The author explains the appearance of patterns on the surfaces of two flat pieces of metal when pressed together at a pressure approaching their yield points, by reference to the difference in hardness of the crystal grains.

An Investigation of Abrasion in Cast Iron. M. Suzuki. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Nov., pp. 121–129). (In Japanese). The author tested the relative abrasion resistance of a number of grey cast irons with an apparatus devised by himself. He ascertained that the abrasion was not so much dependent on the hardness and tensile strength as on the chemical composition ; in particular, an increase in the phosphorus content increased the resistance to abrasion.

On the Study of Abrasion Mechanism at the Japan Society for the Promotion of Scientific Research. K. Asakura. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Nov., pp. 75–76). (In Japanese). The author reports on an investigation of means of reducing the wear of machinery parts. The three aspects considered were the roughness of the contacting surfaces, the fatigue of metals and the chemical effect of oxygen and nitrogen.

Consideration of the Various Phenomena of Metal Wear and Influence of Atmospheres on the Wear of Steel. S. Saito and N. Yamamoto. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Nov., pp. 76–89). (In Japanese). The authors discuss the factors influencing the wear of metals by abrasion and describe some experiments in which the effect of conducting the tests in a vacuum, in hydrogen and in nitrogen are compared.

Further Experiments on the Pitting of the Metals. T. Nishihara and T. Kori. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Nov., pp. 89–97). (In Japanese). The authors report on some experiments in which they tested the influence of constant and intermittent lubrication on the pitting of a pair of

steel cylinders rotating in contact. They found that excess of lubrication promoted pitting.

On the Change of Hardness Caused by Repeated Stress and the Effect of Ageing on Its Recovery. F. Ôshiba. (Science Reports of the Tôhoku Imperial University, 1940, vol. 28, Feb., pp. 370–385). The author reports on his investigation of the changes in hardness of steel specimens during a fatigue test and of the effect on the course of the hardness fluctuations of interrupting the fatigue test with varying periods of rest. Flodin iron (an almost pure iron) and steels containing 0·1% and 0·3% of carbon were used for the tests.

On the Magnetic Viscosity of Single Crystals of Iron. T. Nishina. (Science Reports of the Tôhoku Imperial University, 1939, vol. 28, Oct., pp. 217–224). The author reports on an investigation undertaken to determine the magnetisation time-lag of rods (4 mm. in dia.) of a single crystal of iron at the temperature of liquid nitrogen (− 195·7° C.) by the magnetometric method. The axes of the rods were made almost to coincide with the direction of the principal axes of the crystal. The direction of the crystallographic axes was determined and the time-lag in magnetisation was measured in magnetic fields of different strengths. The results are given in tables and some are plotted as time-magnetisation curves.

On the Change of the Torsional Modulus of some Ferromagnetic Substances with the Temperature and with the Magnetisation. T. Hibi. (Science Reports of the Tôhoku Imperial University, 1940, vol. 28, Mar., pp. 435–449). The author reports on an investigation of the changes in the torsional modulus of wires made of nickel, iron, iron-nickel and nickel-copper alloys with temperature and in magnetic fields of different strengths.

On the Change of the Damping Coefficient Due to the Magnetisation of Some Ferromagnetic Substances. T. Hibi. (Science Reports of the Tôhoku Imperial University, 1940, vol. 28, Mar., pp. 450–457). The author describes some experiments undertaken to observe how changes in the strength of a magnetic field would affect the torsional oscillations of wires made of nickel, a nickel-iron alloy and a nickel-copper alloy. He found that the damping coefficient in a magnetic field of constant intensity depends upon the amplitude of the oscillations, and it appears that there are two or three ranges of amplitude in which the damping coefficient is of a nearly constant value.

Magnetic Materials for Relay Cores and Similar Uses. H. H. Meyer and H. Fahlenbrach. (Technische Mitteilungen Krupp, Technische Berichte, 1940, vol. 8, Apr., pp. 29–32). The authors report on the development in the manufacture of Hyperm alloys, which are alloys of low coercive force produced by the Krupp A.-G. They deal in particular with Hyperm 0 and Hyperm 7. The former is a practically pure iron subjected to a special annealing process, and its properties are said to be superior to those of the Swedish soft iron formerly used. The latter is an iron-silicon alloy the coercive

force of which is as low as 0·06 oersted, *i.e.*, a value which could formerly be reached only by using nickel as an alloy constituent. In conclusion the authors point out that the use of nickel-bearing Hyperm alloys (Hyperm 36, 50, 366, 702 and 766) is therefore only justified for some special purposes while nickel is so scarce in Germany.

Thermal Expansion of Some Chromium-Vanadium Steels. P. Hidnert. (Journal of Research of the National Bureau of Standards, 1940, vol. 24, Jan., pp. 25–30). The author gives the results of determinations of the expansion coefficients of five specimens of S.A.E. chromium-vanadium steels (chromium about 1% and vanadium 0·17%) at temperatures between 20° and 650° C.

Creep of Torsion. A. Simizu. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Nov., pp. 130–136). (In Japanese). The author reports on and discusses the results of creep-torsion tests carried out at 450° C. on steel specimens of eight different analyses.

Effect of the Composition upon the Creep Properties of Carbon Steel. A. Simizu. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Nov., pp. 136–139). (In Japanese). The author reports on his investigation of the effect of the carbon content of steel on the creep-torsion properties at 450° C.

The Properties of Some Nickel-Molybdenum Cast Irons. M. Ballay and R. Chavy. (Revue du Nickel, 1939, vol. 10, Nov.-Dec., pp. 162–171). The authors discuss the properties of a number of special irons, some cupola-melted and others crucible-melted, containing up to 4·2% of nickel and up to 0·71% of molybdenum.

Hypersilid—A High-Silicon Acid-Resisting Alloy. (Metallurgia, 1940, vol. 21, Feb., p. 102). The general physical properties of Hypersilid are enumerated. This is a corrosion-resistant high-silicon cast iron, which is manufactured by Bradley and Foster, Ltd., by a new and special process not described in the note. The composition of Hypersilid is within the limits of the normal high-silicon cast irons, and the improvements effected by the new process lie in the casting properties, soundness and strength of the alloy. Outstanding disadvantages of Hypersilid are excessive hardness and brittleness.

Alloy Cast Iron in Railroad Equipment. A. Reyburn. (Canadian Metals and Metallurgical Industries, 1940, vol. 3, Feb., pp. 52–58). The author describes the properties of a high-strength cast iron developed at the foundry of the Canadian National Railways and the cupola practice employed for its production. A high percentage of steel is charged and the analysis of the finished iron is : total carbon 3·00–3·20%, silicon 0·80–1·10%, manganese 0·80–1·00%, nickel 0·75%, sulphur 0·110% max., and phosphorus 0·20% max.

Alloy Cast Irons in Steel Works Plant. A. B. Everest. (Journal of the West of Scotland Iron and Steel Institute, 1939, vol. 47, Dec., pp. 33–38). After discussing some of the general properties of low-

alloy, heat-treatable and austenitic cast irons, the author describes a variety of applications of alloy cast irons in steelworks plant.

Air-Hardening Die Steel. (Iron Age, 1940, vol. 145, Mar. 7, p. 53). A description is given of the properties of a new air-hardening tool steel manufactured by the Bethlehem Steel Company which is intended for making dies, punches, &c. It has the following approximate analysis : carbon 1%, manganese 2%, chromium 2% and molybdenum 1%. The characteristics claimed for the steel are : (*a*) Good hardenability when air-quenched as compared with certain liquid-quenched steels ; (*b*) low quenching temperature, *i.e.*, from 1550° to 1625° F. ; (*c*) satisfactory machinability in the annealed state ; (*d*) high resistance to wear ; (*e*) ease of heat treatment ; and (*f*) good hardness penetration.

Recent Trends in Corrosion-Resisting and Heat-Resisting Steels. J. H. G. Monypenny. (Metal Treatment, 1940, vol. 6, Spring Issue, pp. 3–7, 10). The author surveys some recent developments in the manufacture of corrosion- and heat-resisting steels, and discusses in turn the effect of nitrogen in high-chromium irons, the addition of copper to martensitic steels, free-cutting stainless steels, intercrystalline corrosion, chromium-manganese steels, and the development of brittleness as a result of the formation of the σ-phase based on a compound FeCr. The author points out that investigations of the temperatures and speed of formation of this σ-phase have shown that it is formed from ferrite and not from austenite, and that those metals which produce ferrite when added to austenitic chromium-nickel steels may also lead to the formation of the σ-phase if the steels are held for prolonged periods at a dull red heat, thus rendering them brittle.

Silicon-Molybdenum-Vanadium Steels. (Alloy Metals Review, 1940, vol. 3, Mar., p. 1). Particulars are given of the properties of two new steel alloys developed in the United States. The analyses are : carbon 0·60% and 0·55%, manganese 0·90% and 1·04%, silicon 2·25% and 2·00%, molybdenum 1·20% and 1·33%, and vanadium 0·50% and 0·50% respectively. The former has been successfully used for coal-cutting bits and the latter for hammer heads.

Hi-Tensile Steel Ships. G. de Rooy and P. Schoenmaker. (Steel, 1940, vol. 106, Mar. 18, pp. 56–58, 83 ; Mar. 25, pp. 68–71, 75). In the first part of their paper the authors describe and discuss the physical properties of high-tensile steels containing low percentages of copper, chromium, molybdenum and nickel. They then deal with the welding properties of these steels and describe and illustrate several designs of joint used in shipbuilding work. In conclusion they mention some of the advantages of using welded high-tensile steel in the construction of submarines and other naval vessels.

METALLOGRAPHY AND CONSTITUTION

The Optics of the Electron Microscope. L. C. Martin. (Journal of the Royal Microscopical Society, 1939, vol. 59, Dec., pp. 217–231). The author describes the electron microscope at the Imperial College of Science and Technology, London, and analyses the possible causes of the appearance of marked astigmatic streaks in the second stage of magnification of this apparatus.

Metallographic Grinding with Abrasives Fixed in Lead Disks. K. Amberg. (Metals Progress, 1940, vol. 37, Feb., pp. 146–149). An abridged English translation is presented of Amberg's paper which appeared in Jernkontorets Annaler, 1937, vol. 121, No. 9, pp. 603–604. (*See* Journ. I. and S.I., 1938, No. I., p. 156 A).

Electrolytic Polishing in the Laboratory and in Industry. (Metal Treatment, 1940, vol. 6, Spring Issue, pp. 21–25). The Allegheny-Ludlum and the Jacquet and Rocquet processes for the electrolytic polishing of steel are described and discussed. Accounts of these processes have been published previously (*see* Journ. I. and S.I., 1940, No. I., pp. 246 A and 260 A).

An Improved Polishing Machine for Micro-Sections. A. Blainey. (Metallurgist, 1940, vol. 13, Apr., pp. 111–112). A new type of polishing machine is described in which the specimens are moved over the polishing cloth with a steady rotary motion, the speed of which can be varied over a wide range. Preliminary grinding on emery cloth or paper can be carried out on the same machine. A great number of specimens can be treated simultaneously, and it is not necessary for them to be of the same size or circular in section. In conclusion the author describes in detail the procedure for the preparation of a microsection with the new machine.

The X-Ray Penetration of Steel Using X-Ray Tubes with up to One Million Volts. R. Berthold, F. Ebert and O. Vaupel. (Stahl und Eisen, 1940, vol. 60, Apr. 18, pp. 339–341). The authors describe some experiments undertaken to determine the maximum thickness of steel which could be penetrated by a 1000 kV. X-ray apparatus. They describe the apparatus briefly. The distance of the films from the X-ray source was 100 cm. and a steel specimen was prepared so that the thickness increased in 5 mm. steps. They found that thicknesses of 220–230 mm. of steel could be penetrated. Further experiments to ascertain the minimum difference in thickness which could be revealed by a radiograph showed that this was 2·4% of the total thickness of the test block when no filter was used, and 1·6% when a 1-mm.-thick lead filter was used.

X-Ray Inspection. H. R. Isenburger. (Steel, 1940, vol. 106, Apr. 1, pp. 64–68). The author describes the principles of the

application of X-rays to the detection of faults in steel. He also explains a technique of double exposure by which the depth of a revealed defect can be determined within about 10 min. of making the exposures.

An X-Ray Diffraction Study of Grain Boundary Inclusions in Steel. R. Morgan, S. Steckler and E. B. Schwartz. (Journal of the Franklin Institute, 1940, vol. 229, Feb., pp. 190–199). The authors studied the composition of the grain-boundary material of a transformer steel and of a commercial low-carbon steel. They treated laminæ (10 × 5 × 0·1 mm.) of these steels with 12% ammonium persulphate solution and subjected the residues to X-ray examination. The residues had the appearance of relatively strong and homogeneous films, which suggested that they consisted largely, if not solely, of grain-boundary material and not of impurities occluded in the grains. The residues from the low-carbon steel were found to consist mainly of ferroso-ferric oxide. In those of the transformer steel titanium carbide could be identified, but no X-ray patterns of any silicon compound were observed, although spectrum analysis had indicated that silicon was the main component of the grain-boundary material of the transformer steel examined. The authors conclude that silicon is present in the form of amorphous material. The results of the investigation are compared with those of Colbeck, Craven and Murray (*see* Journ. I. and S.I., 1936, No. II., p. 251).

Undercooling of Liquid Steel. (Metallurgist, 1940, vol. 13, Apr., pp. 102–104). This is an abridged translation of Bardenheuer and Bleckmann's paper entitled " The Problem of Primary Crystallisation of Steel : The Undercooling Capacity and the Formation of Nuclei in the Liquid State," which was published in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 13, pp. 201–212. (*See* Journ. I. and S.I., 1939, No. II., p. 298 A.)

The Decomposition of Pearlite in Grey Cast Iron. A. A. Timmins. (Iron and Steel Institute, 1940, this Journal, Section I.). A study was made of some of the conditions governing the decomposition of pearlite in grey cast iron. For this purpose three irons, differing only in silicon content, were heated at constant temperatures for various periods of time. Sections of the corresponding bars in the annealed condition were also similarly heated. Data were obtained which confirm the assumption that the removal of pearlite on annealing at constant temperature depends on the diffusion of carbon through the iron. The results show that combined carbon can be removed quite readily by annealing at temperatures below the critical point of the iron, the rate of removal being more rapid the nearer the heating temperature is to the critical point. It is also shown that heating at temperatures above the critical point may or may not remove combined carbon, depending on whether or not the combined-carbon content is above or below the equilibrium percentage. When heating at these temperatures

the rate of cooling is the major factor in the removal of pearlite, whilst the duration of the soaking is the most important point to be considered when heating at temperatures below the critical point. The results obtained have a bearing on the softening of cast iron to give good machinability, and show that the most satisfactory temperature for annealing purposes is one near the critical point.

Influence of Rate of Cooling on the Transformations in Chromium Steels. (Metallurgist, 1940, vol. 13, Apr., pp. 105–108). This is a report on investigations published by Rose and Fischer in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 8, p. 133. (*See* Journ. I. and S.I., 1939, No. II., p. 300 A). In conclusion the results of these authors are compared with those obtained by Griffiths, Pfeil and Allen (Second Report of the Alloy Steels Research Committee, p. 343, Iron and Steel Institute, 1939, Special Report No. 24).

Ternary Iron-Cobalt Alloys. (Metallurgist, 1940, vol. 13, Apr., pp. 104–105). This report on recent studies of ternary iron-cobalt alloys briefly reviews the work of W. Köster and G. Becker on the iron-cobalt-tantalum system, the work of Köster on the iron-cobalt-beryllium system, and the investigations of W. Geller on the iron-cobalt-antimony diagram, results on the first two systems having been published by Körber and on the third system by Geller. (*See* Archiv für das Eisenhüttenwesen, 1939–1940, vol. 13, pp. 93, 227 and 263, *also* Journ. I. and S.I., 1939, No. II., p. 301A ; 1940, No. I., pp. 106 A and 212 A).

CORROSION OF IRON AND STEEL

Corrosion Survey. J. H. Bosbyshell and J. S. Yeaw. (American Gas Journal, 1939, vol. 151, Dec., pp. 29–33). This paper forms part of the Report of the Gas Conditioning Committee presented at the American Gas Association Annual Convention held in New York in October, 1939. The authors summarise their observations made in the course of examining 783 refrigerators, house heaters and water heaters with the object of studying the corrosion resulting from the combustion of natural gas. The authors came to the following conclusions : (1) The condensation of vapours formed during the combustion of gaseous fuels containing sulphur causes corrosion in the combustion chamber and flue pipes ; (2) to prevent corrosion the amount of sulphur in the gas must be reduced considerably below 2 grains per 100 cu. ft. ; and (3) other constituents of the products of combustion do not appear to be significant with respect to corrosion.

A Study of the Beginning of the Corrosion of Iron with the Aid of the Photo-Electric Determination of Iron as Sulphide. K. Damaschke and F. Tödt. (Korrosion und Metallschutz, 1940, vol. 16, Apr., pp. 109–116). The authors review the methods so far used for the study of the commencement of corrosion, and they describe a new method based on the photo-colorimetric determination as sulphide of traces of iron dissolved. They report on the results obtained when studying the corrosion of four different qualities of iron, specimens of which were exposed for a few minutes to various corrosive agents. They found that the corrosion in the very beginning is about a hundred times greater than it is after a time interval. After 1 min. the corrosion is about one-third and after 10 min. about one-tenth of that at the commencement. The authors believe the heavy initial corrosion to be due to hydrogen over-voltage and to oxygen depolarisation, assuming that, in addition to the well-known depolarising effect of oxygen dissolved from the air, there might also be a noticeable influence of the oxidised surface layer of the iron.

Some Experiments Carried Out in order to Find Low-Friction Corrosion-Resistant Alloys. C. H. Meyer. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Apr., pp. 437–444). In order to establish the suitability for their use as machine bearings in the chemical industry the author studied the frictional properties and the corrosion resistance of a great number of alloys, *viz.*, 32 different grey austenitic nickel cast irons, 8 high-chromium cast irons and several commercial bearing metals. For the corrosion tests cylindrical specimens 25 mm. in dia, and 5 mm. in length were used

and exposed for a maximum duration of 96 hr. to the attack of the following corrosive agents in a variety of concentrations : hydrochloric, sulphuric, sulphurous, phosphoric and acetic acids, as well as sodium hydroxide and magnesium chloride. The frictional properties were determined with the help of a complicated device, a diagram of which is given, which allowed the measurement of the frictional forces occurring in the bearing. Grey austenitic nickel cast irons proved to have good frictional properties, provided that they did not contain too large graphite inclusions. Their frictional properties could be improved further by the use of hardened shafts and by small additions of antimony. Grey nickel cast irons were extremely resistant to alkalis, even at high temperatures. Their acid resistance was not so great, neither could it be improved to any important extent by increasing their chromium content. Additions of copper, however, increased the resistance to sulphuric acid, and additions of molybdenum and, in particular, of antimony increased the resistance to hydrochloric acid. As material for bearings in the nitric-acid industry only high-chromium alloys proved to be suitable. The frictional properties of carbide-ferritic chromium cast iron proved to be much superior to those of austenitic chromium-nickel cast steel. Austenitic-ferritic chromium-manganese cast steel has rather good frictional properties however.

Mild Steel for Chemical Plant. (Metallurgist, 1940, vol. 13, Apr., pp. 101–102). This is an abridged translation of the paper entitled " The Alkali-Resisting Properties of Mild Steel in Relation to Ageing Tendency, Heat Treatment and Aluminium Content," published by Nehl and Werner in Stahl und Eisen, 1939, vol. 59, Oct. 19, p. 1155 (see Journ. I. and S.I., 1940, No. I., p. 107 A). In conclusion it is stated that the authors' results are in agreement with opinions held in Great Britain.

Some Experiments to Establish the Passivating Effect of Activated Carbon Saturated with Ammonia. P. Prill and E. Böhm. (Korrosion und Metallschutz, 1940, vol. 16, Mar., pp. 86–88). The authors compare the time-potential curves of polished iron and of iron specimens painted with linseed oil varnishes containing, respectively, red lead, ferric oxide and activated carbon saturated with ammonia. The electrolyte used was in all cases $0.01N$ potassium chloride solution. After having found that ferric oxide had no passivating influence, the authors added it to the activated-carbon paints in order to thicken them. The results clearly indicated that activated carbon saturated with ammonia has a similar passivating effect to that of red lead. This effect is due to the ammonia treatment, as is indicated by the negative results obtained when using ordinary activated carbon.

The Effect of Gases Containing Hydrogen Sulphide on Iron and Some Ferrous Alloys. W. Baukloh and E. Spetzler. (Korrosion und Metallschutz, 1940, vol. 16, Apr., pp. 116–121). The scaling due to the effect of hydrogen sulphide diluted with hydrogen and

nitrogen, respectively, was studied on Armco iron and on iron alloyed with manganese, chromium, silicon, nickel and a high percentage of carbon, respectively. The authors found, in agreement with results of previous investigators, that iron alloyed with aluminium or chromium is very resistant to the corrosive effect of hydrogen sulphide. The resistance is also increased by a high percentage of carbon, whereas additions of silicon and nickel have little protective effect, and manganese is effective only if added in amounts greater than 21%. It was generally found that at high temperatures the attack by hydrogen/hydrogen-sulphide mixtures was greater than that by nitrogen/hydrogen-sulphide mixtures, whereas at low temperatures the attack by the latter was greater than that by the former. In conclusion the authors describe the appearance of various specimens after the scaling tests.

A Note on the Corrosion of Compressor Housings in Refrigerators. F. Roll. (Korrosion und Metallschutz, 1940, vol. 16, Apr., pp. 133–136). The author studied the causes of the corrosion sometimes observed in the compressor housings of refrigerators the cooling agent of which is liquid sulphur dioxide. They found that sulphur dioxide has a corrosive effect only in the presence of water, which leads to the conclusion that only perfectly dry sulphur dioxide should be used. It is also likely that other impurities in sulphur dioxide, e.g., sulphuric acid and sulphur trioxide have a deleterious effect. High-duty cast iron proved to be more resistant to the influence of moisture-containing sulphur dioxide than another quality studied which had a coarse graphite structure.

A Note on the Caustic Embrittlement of Boiler Plate. G. T. Athavale and W. Eilender. (Korrosion und Metallschutz, 1940, vol. 16, Apr., pp. 127–132). Experimental data obtained by the authors show that there is no direct relation between the McQuaid-Ehn grain size, the ageing and the caustic embrittlement of steel. The nitriding of steels prone to caustic embrittlement had a favourable influence, however. The resistance was also increased by a medium rate of cooling down from the normalising temperature and by quenching with subsequent annealing at 650° C., whereas cold-working had a deleterious effect. A content of more than about 0·05% of metallic aluminium proved to be most effective in preventing the caustic embrittlement of mild steel, whereas an alumina content is very undesirable.

Pinhole Corrosion in Galvanized Watering Tanks. W. M. Peirce and G. C. Bartells. (Metals and Alloys, 1940, vol. 11, Feb., pp. 42–44). The authors report on their investigation of the causes of pinhole corrosion in galvanised sheets used for water tanks. They examined seven samples from tanks which had given good service for about 22 years and seven others from tanks which had pitted through in about 1½ years. They found that differences in the water bore no relation to the occurrence of corrosion, but analyses showed that the coating on the former specimens never contained more

than 0·28% of tin, and that on the latter never less than 0·54% of tin. The authors therefore conclude that the higher tin content caused the trouble, and, bearing on this, they point out that in 1938 the average tin content of the zinc used for galvanising was nearly 0·50%, whilst in 1928 it was only 0·05%.

Corrosion Troubles in Heating and Hot Water Systems. L. Kenworthy. (Journal of the Institution of Heating and Ventilating Engineers, 1940, vol. 8, Mar., pp. 15–33). After a general consideration of the theory of corrosion the author discusses some practical corrosion problems associated with (a) copper, (b) iron, (c) galvanised iron, (d) copper and galvanised iron in the same installation, and (e) brass.

Electrolytic Corrosion of Ship Structures. J. H. Paterson. (Institution of Engineers and Shipbuilders in Scotland : Iron and Coal Trades Review, 1940, vol. 140, Apr. 12, pp. 573–574). The author explains the mechanism of electrolytic corrosion by reference to the order of metals in the electrochemical series and on this basis he explains the causes of local corrosion phenomena observed in ship structures.

Copper Steels. C. T. Greenidge and C. H. Lorig. (Iron Age, 1940, vol. 145, Feb. 15, pp. 21–25). The authors report on the results of three-year atmospheric corrosion tests on 43 different plain and low-alloy steels with additions of up to 1·5% of copper. They give the results in tables and graphs, and from these arrive at the following general conclusions : (1) Additions of 0·20–0·50% of copper markedly increase the corrosion resistance. Greater additions increase this property still further, but the improvement is then small ; (2) additions of 0·20–0·50% of copper improve the corrosion resistance of steel containing silicon 0·61%, chromium 0·96% and phosphorus 0·14% ; (3) chromium and phosphorus reduce the rate of corrosion of copper-silicon steels ; and (4) small amounts of tin, aluminium, nickel or silicon in copper-bearing, low-carbon steel have little effect on its corrosion resistance.

Corrosion under Protective Coatings. J. K. Wirth. (Korrosion und Metallschutz, 1940, vol. 16, Mar., pp. 69–76). It is known that organic-base coatings (e.g., linseed oil paints) protect metal from corrosion not so much because they keep the moisture from direct contact with the metal, but because the interface between the metal and the coating possesses some particular protective properties. The author therefore undertook some " ion-penetration " experiments by constructing cells with a coated iron plate as one electrode and a noble metal as the other, and tap water as the electrolyte. He measured the current generated and constructed ion-penetration curves by plotting the current (in 10^{-10} amp. per sq. cm.) against time. These curves showed the total effect of both the coating and the boundary layer. In order to determine the influence of the boundary layer the author carried out two series of similar experiments, using in one series cells as previously described and in the

other series cells with uncoated iron as one electrode, whilst separating this from the noble metal there was a cellophane diaphragm with a coating of the same material and thickness as that applied to the iron electrode in the complementary experiment.   He discusses the results obtained using red-oxide and zinc-oxide paints and varnishes. These demonstrated in all cases that the degree of ion-penetration was infinitely less when there was a continuous protective coating adhering to the iron than when a coating of the same material and thickness was placed in the electrolyte as a barrier to the movement of the ions.

The Behaviour of Electrodeposited Zinc Coatings under Various Corrosive Conditions.   J. Korpiun.   (Metallwirtschaft, 1939, vol. 18, Dec. 19, pp. 1024–1026).   The author gives an account of two series of corrosion tests.   In the first series the behaviour of test-pieces of iron sheet coated with (a) zinc, (b) zinc with a bright chromium surface layer, and (c) nickel with a bright chromium surface layer was compared.   The test-pieces were subjected to intermittent immersion in 3% sodium chloride solution for twelve days and in distilled and tap water for three months.   In the second series of experiments a comparison was made of the atmospheric corrosion of test-pieces which were bright cadmium-plated, bright nickel-plated with a chromium surface layer, bright zinc-plated with a chromium surface layer and bright zinc-plated with a lacquer coating.   The results showed that bright zinc-plating afforded the same protection as bright cadmium-plating in all the cases studied. The corrosion resistance of the zinc coating was increased considerably by a chromium surface layer, and this combined zinc-chromium coating proved to be superior to a nickel-chromium coating in long-time corrosion tests.   The results obtained with lacquered galvanised sheets were also very satisfactory.   This method of protection is, however, only suitable for articles which are not exposed to mechanical wear.

Investigation of Old Iron Parts from Cologne Cathedral.   K. Daeves.   (Stahl und Eisen, 1940, vol. 60, Mar. 21, pp. 245–252). The author describes an investigation of some pieces of iron taken from Cologne cathedral.   These had been exposed to weathering for about 500 years.   Full particulars of the analyses are given and tables are presented of the analyses of many museum specimens, and the probable processes of manufacture are discussed.

BOOK NOTICES

HEYER, R. H. "*Engineering Physical Metallurgy.*" 8vo. pp. viii + 549. Illustrated. London, 1940 : Chapman and Hall, Ltd. (Price 25s.)

In the preface to this book the author states that " although published information of a high order is available there have been few attempts to condense, correlate and bring up-to-date the various materials, methods and concepts of metals technology." The first part of this statement is certainly true, for no one can doubt the extent and value of the information now available on physical metallurgy in hand-books, monographs, the transactions and proceedings of technical societies and the regular metallurgical periodicals. There is, however, room for a difference of opinion about the truth of the statement that there have been few attempts to condense, correlate, &c. The present work is designed to aid those making their first acquaintance with engineering metals and alloys, and the author has endeavoured to produce a simple treatment of this field and to adapt it to the instruction of non-metallurgical students. In stating that there have been few attempts to condense, correlate, &c., he evidently means that there have been few attempts to do what he has done. Whether this is true or not depends to a great extent on what is meant by few, but it does seem that a substantial proportion of the total American and British output of metallurgical books in recent years has been directed to the same general object as the present volume. The book deals in the first place with the crystal structure of metals, the growth of dendrites, deformation and recrystallisation, and failure under static and repeated stress. All this is done in the first chapter, which is entitled " Pure Metals " and occupies twenty-one pages. The second chapter is called " Principles of Alloying." It likewise occupies twenty-one pages, and discusses binary alloy systems and the relations between the constitutional diagram and the observed structures; solid solutions; and intermetallic compounds. The remainder of the book is devoted to the consideration of specific alloys and treatments, *i.e.,* bearing metals, light alloys, copper and its alloys, cast iron, carbon and alloy steels, die casting, welding, and the heat treatment and surface treatment of steel. This major portion of the book, which deals with specific alloys and treatments and occupies four hundred and ninety pages, is of considerable value because it is well arranged, well illustrated, right up-to-date, and accompanied by comprehensive selections of references. Anyone who has not kept up with developments as recently reported in American publications will find this book very useful, and even those who have may welcome the work as a guide to references they have forgotten. If, however, the book is judged as a volume that has to be used by an engineer who has not studied other books or had much instruction in metallurgy, it appears less satisfactory, for the fundamental aspects of physical metallurgy are not dealt with fully enough to enable such a reader to appreciate the more practical chapters as he might do. As it is evident that even the largest book cannot deal with the whole of physical metallurgy, and as this is not a very large book, it is no criticism to say that in order to deal fully with some subjects others have had to be condensed or omitted. Every

book is open to criticism on these lines, and it can be said of the present book that it does give a good account of the subjects in which the author is at present interested.   J. M. ROBERTSON.

Low, K. S. " *Metallurgical and Industrial Radiology.*" Sm. 8vo. pp. vii + 88. Illustrated. London, 1940 : Sir Isaac Pitman & Sons, Ltd. (Price 7*s.* 6*d.*)

The use of X-rays in the study of metals has been very much in the news during the last twenty years, and an extensive literature on the subject is now in existence. Many who have skimmed over or plodded through some of the larger books or papers on the subject will be surprised to find that an attempt has been made in a small book like this to deal with metallurgical radiology in a manner that will appeal to the metallurgical community in general and not to the specialists alone. It must be remembered, however, that radiology does not include the use of X-rays in the study of the crystal structure of metals and alloys and the effect on this of mechanical working, heat treatment and applied stress. It is concerned only with the use of X-rays in detecting fissures, cavities and accumulations of inclusions in welds and castings (and more rarely in worked products), and can therefore be dealt with without considering the more difficult aspects of the use of X-rays in the study of metals. The general principle of metallurgical radiology is simple, and development of the subject has depended mainly on the development of powerful, safe and easily manipulated equipment. This aspect could not be properly discussed in a short and popular book, but regarding the design and manufacture of the equipment as mainly the business of the firms who have specialised in this, it is quite possible, as the author of the present work has shown, to discuss the general principles and technique of radiology and the interpretation of radiographs in a manner that will be understood by metallurgists and engineers in general. The actual chapter headings in the book are : Introduction; General Principles; Apparatus and Equipment; Accessories, Appliances and Materials; Radiographic Technique; Interpretation of Radiographs; Industrial Fluoroscopy; Radiological Examination of Welds; and, Determination of Measurements—Stereoscopy—Tomography. It is becoming more widely realised that engineering design and production can be made much more efficient when the degree of soundness and cleanness of actual components can be ascertained, and it is also being more generally appreciated that casting and welding technique can be rapidly improved when a method is available for inspecting the interior of the metal. As a result radiology is being more widely used in the metallurgical industry. It follows, therefore, that an increasing number of technical people are having to consider when, where and how radiological inspection should be introduced, and are having to decide which defects revealed by this method are serious and which are not. Unless they have already made a study of radiology all those people will find the present book very useful, and others may be recommended to read it in preparation for the time when they also have to recommend radiological inspection, or make a decision on the basis of radiographs.

                                            J. M. ROBERTSON.

SOCIETY OF CHEMICAL INDUSTRY. " *Reports of the Progress of Applied Chemistry.*" Vol. XXIV. 1939. 8vo. pp. 756. London : Society of Chemical Industry. (Price 7*s.* 6*d.* to Members of the Society, 12*s.* 6*d.* to others.)

This volume consists of surveys by leading authorities on the progress during the past year of applied chemistry in its numerous branches.

Many of the reports contained in the present volume are of interest to those engaged in the manufacture of iron and steel. A complete list of the contributions is as follows : General, Plant, and Machinery, by M. B. Donald; Fuel, by H. J. Hodsman, E. W. Claydon and J. S. Forsyth; Gas, Destructive Distillation, Tar and Tar Products, by H. Hollings and W. A. Voss; Mineral Oils, by W. W. Goulston; Intermediates and Dyes, by E. H. Rodd, M. Lapworth and F. Irving; Fibres, Textiles, and Cellulose. The Protein Fibres, by C. S. Whewell and J. B. Speakman; Cellulose Textile Chemistry, by R. J. B. Marsden; Pulp and Paper, by R. A. Ainslie; Acids, Alkalis, and Salts, &c., by P. Parrish and F. C. Snelling; Glass, by A. Cousen; Refractories, Ceramics, and Cement, by J. A. Sugden; Iron and Steel, by S. J. Kennett; Non-Ferrous Metals, by A. R. Powell; Electrochemical and Electrometallurgical Industries, by J. W. Cuthbertson; Oils, Fats, and Waxes, by T. P. Hilditch; Plastics, by Members of the Plastics Group; Resins, Drying Oils, Varnishes, and Paints, by Members of the Oil and Colour Chemists' Association; Rubber, by T. L. Garner; Soils and Fertilisers, by G. V. Jacks; Sugars, by D. Lever; The Fermentation Industries, by A. A. D. Combie; Foods, by T. Moran; Fine Chemicals, Medicinal Substances, and Essential Oils, by H. Paget and T. M. Sharp; Photographic Materials and Processes, by A. Batley; Sanitation, Water Purification, &c., by J. H. Coste; Leather and Glue, by W. R. Atkin.

" *Welded Steel Structures*." Compiled by The Broadway Advertising Service, Ltd. 4to. pp. 75. Illustrated. London, 1940 : The Broadway Advertising Service, Ltd.

This publication illustrates and describes recent developments in the use of iron and steel in structural engineering, and shows a number of examples of modern design. The book contains the following contributions : A Historical Note on the Use of Iron and Steel in Structural Engineering, by S. B. Hamilton; Welding Fabrication, by J. Wright; Welded Steel Frame Buildings, by C. W. Hamann; The Welded Arch in Building Construction, by P. C. G. Hausser; Diagrid Structures, by A. Pandya and R. L. Fowler; Welding and the Mopin System, by H. M. Puddy; Special Types of Welded Structures, by A. G. Grant; Welded Bridges in Great Britain, by T. C. Grisenthwaite; The Strengthening of Iron and Steel Bridges, by A. Goelzer.

REFRACTORY MATERIALS

Basic Refractories in Canada, 1914 and 1939. F. E. Lathe. (Canadian Mining and Metallurgical Bulletin, 1940, Mar., No. 335, pp. 83–99). After reviewing the fluctuations in the production in Canada of magnesitic dolomite and chrome ore from 1907 to 1939, the author gives some particulars of the large deposits of magnesitic dolomite at Kilmar, Quebec, and then describes the various magnesite and chrome bricks and cements which have been developed in Canada in the period 1914–1939.

Refractories Research in the Steel Works. J. H. Chesters. (Proceedings of the Cleveland Institution of Engineers, 1939–1940, No. 3, pp. 103–118). After stating that research on steelworks refractories involves work of two kinds, $viz.$, fundamental work often requiring a long time, and work to solve the immediate problems of industry, the author gives examples of both kinds which have arisen in the course of his own experience. He describes first how a three-dimensional diagram of the FeO–Al_2O_3–SiO_2 system was constructed with the ternary melting-point diagram as a base. A study of this diagram showed that an increase in alumina content, from say 30% to 40%, would result in increased resistance to attack, because the more aluminous material would require more iron oxide to reduce its melting point to the furnace temperature. It also showed that the ternary eutectic contained only about 10% of alumina, so that melts containing more or less of this oxide would be more refractory. Secondly, he describes tests made to ascertain whether used checker bricks, even though free from dust and unglazed, are unsuitable for further service ; the answer to this was that they could be used without loss of operating efficiency. In this case the results were applied in practice without any apparent effect on the behaviour of the open-hearth furnaces and a very considerable saving resulted. In conclusion the author describes a simple and fairly rapid test by which the thermal shock-resistance of refractory bricks can be measured.

Study of the Recrystallization of Magnesia. H. G. Schurecht and V. D. Fréchette. (Journal of the American Ceramic Society, 1940, vol. 23, May, pp. 134–136). The authors report on an investigation of the nature of the transformation of magnesia to periclase and of the lowest temperature at which the change will take place. Three commercial crude magnesites from Washington, California and Greece were fired for 4 hr. at temperatures rising from 800° to 1400° C. in stages of 100° C. The periclase crystals could be clearly distinguished

under the microscope in all the samples fired at 1300° and 1400° C., but it was impossible to resolve the crystals in samples fired below 1300° C. Examination of the X-ray diffraction patterns showed that the magnesites fired for 14 hr. at 750° C. no longer had the crystal structure of magnesite ($MgCO_3$) but had clear sharp lines the positions and intensities of which were characteristic of periclase. The evidence obtained by X-rays also proved that lightly calcined magnesite is not amorphous but cryptocrystalline with a particle size in the colloidal range.

Carbon Linings for Blast-Furnaces. F. J. Vosburgh. (Iron and Steel Engineer, 1940, vol. 17, Apr., pp. 68–72). The author discusses the use of carbon blocks for lining blast-furnace hearths. The information given is based on German practice, as this material has not found favour in the United States for this purpose. Three types of carbon lining have been tried. At first carbon bricks the same size as refractory bricks were used, but these were soon superceded by larger machined blocks; the third type was made by tamping a carbon paste over the surface of a carbon-brick lining. Little information is as yet available about the results achieved with the third type, but the use of large machined blocks seems to give the most satisfactory service, and it is reported that about 75% of the blast-furnaces in Germany are constructed with a carbon-block lining up to the mantle.

Refractory Materials for Reverberatory Furnaces. A. B. Searle. (Metallurgia, 1940, vol. 21, Feb., pp. 129–131). The author discusses the refractory materials used for a reverberatory furnace, dealing separately with the requirements for the fuel hearth, bridge, metal hearth, nozzles, side walls, roof and flue. He emphasises the importance of careful selection of refractory material for each particular part of a furnace to ensure economical service.

Sprung-Arch Roofs of High Temperature Furnaces. J. S. McDowell. (Blast Furnace and Steel Plant, 1940, vol. 28, Feb., pp. 161–168, 178 : Heat Treating and Forging, 1940, vol. 26, Feb., pp. 91–99). Conclusion of a series of articles (*see* Journ. I. and S.I., 1940, No. I., p. 2 A). In the third part of this series of articles the author gives some examples of the calculation of stresses in the arches of open-hearth furnaces.

Soaking-Pit Refractories. E. C. Hite and G. Soler. (British Steelmaker, 1940, vol. 6, May, pp. 123–124). The authors discuss the application of particular types of refractory bricks to the lining of soaking pits.

Heat Insulation. E. T. G. Emery. (Engineering and Boiler House Review, 1940, vol. 53, Mar., pp. 469–474 ; Apr., pp. 546–552). The author considers the thermal conductivity and applications of a variety of insulating materials for use at temperatures up to about 1000° F. The materals include cork, slag wool, expanded rubber, magnesia, kieselguhr, asbestos, aluminium foil and glass silk.

PRODUCTION OF IRON

Foreign Iron Blast-Furnace Practice. W. A. Haven. (Eastern States Blast-Furnace and Coke-Oven Association : Mining and Metallurgy, 1940, vol. 21, Apr., pp. 182–187). The author reviews the present position of pig-iron production and blast-furnace practice in Germany, Russia, Great Britain, the British Colonies, Italy, France, Belgium and Luxemburg.

Some Recent Developments in the Iron and Steel Industry of European Countries. H. A. Brassert. (Eastern States and Chicago District Blast-Furnace and Coke-Oven Associations : Blast-Furnace and Steel Plant, 1940, vol. 28, Jan., pp. 78–81, 105–106 ; Feb., pp. 147–153, 200 ; Mar., pp. 262–263, 269–270, 280 ; Apr., pp. 341, 347–350, 412–413, 422–423). The author reviews the economic position of the iron and steel industry in Europe and relates the position of the various plants to the supplies of ore and fuel. He gives a detailed description of the Stewarts and Lloyds, Ltd., plant at Corby, the Ebbw Vale plant of Richard Thomas and Co., Ltd., and the Hermann Göring plants at Brunswick and Linz. He also discusses the advantages of grading low-grade ores for size, and in this connection describes the Robins-Messiter ore-bedding system which is in use at the works at Linz.

Blast-Furnace Operation Responds to Developments of Past Year. T. L. Joseph. (Blast-Furnace and Steel Plant, 1940, vol. 28, Jan., pp. 31–36, 39 ; Feb., pp. 154–160 ; Mar., pp. 247–248). The author reviews the present position of the Lake Superior iron-ore industry and the development of the magnetite deposits in New York State. He refers to Hewitt's method of determining the value of ore at the blast-furnace (*see* Journ. I. and S.I., 1940, No. I., p. 274 A). He next discusses the production of manganese concentrate in Cuba, which has now reached about 10,000 tons of 50% concentrate per month. He then considers the desulphurisation of pig iron in the ladle with calcium carbide and describes the device used by Wood, Barrett and Holbrook for adding the calcium carbide (*see* Journ. I. and S.I., 1940, No. I., p. 183 A). In the second part of his paper the author considers in turn the necessity of using coke of uniform size in the blast-furnace, the percentage of carbon dioxide in the gas at different distances from the centre of the furnace, the working of the slag and the effect of operating the blast-furnace at higher pressures on the time required to reduce the ore. He concludes this part with a description of the Peabody gas-washer. In the third and concluding part the author describes and illustrates the

Simplex gas-washer ; this is a three-stage washer in a single tower with hot-washing at the bottom, condensing and filtering in the middle, and cold-washing at the top.

The Practical Side of Blast-Furnace Management, with Especial Reference to South African Conditions. R. R. F. Walton. (Iron and Steel Institute, 1940, this Journal, Section I.). After a description of the two South African blast-furnace plants—the Pretoria plant of the South African Iron and Steel Industrial Corporation, Ltd., and the Newcastle plant of its associated company, African Metals Corporation, Ltd.—with details of the furnace lines, the raw materials used are discussed and the unusual nature of these is pointed out. The coke is high in ash and friable, and actual test figures are given, showing the effect on furnace operation of coke breeze of various sizes.

The operation and care of crushing, handling and charging appliances, stoves, Lodge-Cottrell and Theisen gas-cleaning plants and the gas-distribution system are mentioned, and the following section deals with the handling of the furnaces. The method of blowing-in with the usual charge and the results attained are followed by notes on the necessity of regularity of the burden, charging and blast volume. Hanging and slipping and their prevention and cure are discussed, as is the care of the tap-hole, runners and ladles ; a description of the mud-gun, dam and skimmer is included. The precautions taken during a plant stoppage are indicated, and details are given of unusual operating difficulties, including the use of dynamite in the bosh and well of a furnace. After dealing with the operation of the pig-casting machine, the paper ends with a section on the South African personnel and unusual weather conditions.

Details of Design—No. 5 Blast-Furnace, Inland Steel Co. H. W. Johnson. (Iron and Steel Engineer, 1940, vol. 17, Apr., pp. 22–35). The author presents a detailed description of the No. 5 blast-furnace of the Inland Steel Co., Indiana Harbour, and discusses its operation with particular reference to : (a) The equipment for preparing and charging the coke ; (b) the radial distribution of the gases in the stock column ; (c) the influence of the height of the furnace ; and (d) the method of heating and controlling the blast.

Hearth and Bosh Areas. J. P. Dovel. (Steel, 1940, vol. 106, Apr. 22, pp. 60, 64). The author discusses the relationship between the hearth and bosh diameters of a blast-furnace and the effect of this relationship on its efficiency. He explains why a path of low resistance to the upward flow of gases is formed up through about the centre of the stock, and he points out that, as a result of research and observation of the working of a large number of furnaces, he finds it advantageous to design the furnace so that a path of low resistance is created round the wall as well, with the object of causing the stock to settle uniformly as it is reduced in volume.

A Blast-Furnace Turbo-Blower. D. W. Rudorff. (Metallurgia, 1940, vol. 21, Apr., pp. 173–176). The author summarises some unusually exhaustive test reports relating to the performance of a blast-furnace turbo-blower recently installed at the Azov Steelworks at Mariupol in the U.S.S.R. This blower is capable of delivering 140,000 cu. ft. per min. at 34 lb. per sq. in. with a power consumption of about 14,000 kW.

The Working of 930 cu. m. Blast-Furnaces with the Blast Heated to a Higher Temperature. N. Kaystro. (Stal, 1939, No. 9, pp. 1–8). (In Russian). Experimental data characterising the working of No. 1 and No. 2 furnaces at the Voroshilov works in relation to blast temperature are examined. The mean blast temperatures for each day range from about 550° to 700–750° C. The factors dealt with are : production, silicon content of the iron, coke consumption, and quality of the pig iron ; some reference is also made to blast pressure. The effects of changes in blast temperature are illustrated by numerous curves. Optimum operating conditions are suggested on the basis of the data obtained. The latter are also compared with figures published by other investigators. It is concluded that in the production of low-silicon open-hearth pig iron the use of the maximum possible blast temperature (not lower than 700–750° C.) is advisable. The coke consumption is decreased, while there is also a sharper demarcation between the reduction and the slag-formation zones, and the extent of the high-temperature zone is reduced. The use of a high blast temperature entails careful control of certain conditions.

Mineral Wool. M. S. Krishnan. (Transactions of the Mining, Geological and Metallurgical Institute of India, 1940, vol. 35, Feb., pp. 401–428). The author discusses the prospects of the manufacture of glass wool, slag wool and rock wool in India as by-products of the Portland cement industry and of the iron and steel industry. He states that there is a large potential market for such material in India because it is a tropical country where the insulation of structures against heat has scarcely begun.

England's War Economy. P. Osthold. (Stahl und Eisen, 1940, vol. 60, Apr. 18, pp. 333–339 ; Apr. 25, pp. 360–366). The author presents a general review of the administrative structure and the principles on which England's economy in the present war is based, making numerous comparisons with the war of 1914–1918.

The Development of the Ferrous Industry in the Nevers District. Coudert. (Revue de l'Industrie Minérale, Mémoires 1940, Mar., pp. 73–91). After an introductory review of the development of ferrous metallurgy in the Nevers district of France, the author deals at some length with the history from 1637 of the Imphy steelworks, and he finally reports on the development of the special steels produced by these works since the end of the nineteenth century.

FOUNDRY PRACTICE

(Continued from pp. 9 A–10 A)

Fundamentals of Cupola Practice. D. J. Reese. (Foundry, 1940, vol. 68, Apr., pp. 30–32, 92). The author discusses cupola practice, making numerous recommendations as to the technique for heating up, blowing, slagging, reducing the number of inclusions and tapping.

High-Test Iron. J. C. Stavert. (Canadian Metals and Metallurgical Industries, 1940, vol. 3, Mar., pp. 62–65). The author explains the theory of the structure of ordinary and of " high-test " cast iron. He classifies under " high-test " cast iron any which has a tensile strength of 40,000 lb. per sq. in. or more. He shows that the following factors are important in the production of a high-strength iron : (1) The total carbon content must be as low as possible and should not exceed $3\cdot3\%$; (2) a higher silicon content may be used, and the lower the total carbon, the wider the range of silicon which may be employed without materially affecting the strength ; and (3) the sulphur and phosphorus must be kept low and the manganese kept rather high, usually at about $0\cdot8\%$. Having discussed the theory, the author next makes recommendations regarding the correct cupola practice when using a high percentage of steel in the charge. In conclusion he discusses the effects of additions of nickel, copper, vanadium, chromium, molybdenum and titanium.

Steel Foundry Progress in Melting and Heat Treating. E. F. Cone. (Metals and Alloys, 1940, vol. 11, Apr., pp. 99–102). The author analyses some of the information presented in the Directory of Steel Foundries for 1939 published by the Steel Founders' Society of America. He notes that the number of electric furnaces for producing steel castings has risen from 287 in 182 plants in 1929 to 319 in 167 plants in 1939. Statistics relating to open-hearth and heat-treatment furnaces are also given.

Patterns and Castings. C. Joynes. (Institute of British Foundrymen : Foundry Trade Journal, 1940, vol. 62, May 16, pp. 361–363). The author criticises the present organisation of the foundry industry of Great Britain, dealing in particular with unnecessary competition, the need for standardisation, the training of pattern-makers, mechanised production and the design of castings.

Production of Some Engineering Castings. A. Marshall. (Institute of British Foundrymen : Foundry Trade Journal, 1940, vol. 62, Apr. 18, pp. 289–291 ; Apr. 25, pp. 311–313). The author

describes the moulding technique for the production of some large engineering castings, including a machine-tool bed, a cylinder for a marine steam engine, a Diesel-engine scavenge-pump cylinder and some frames and beds for wood-working machinery.

Local Densening of Iron Castings. G. Longden. (Foundry Trade Journal, 1940, vol. 62, May 16, p. 368). The author describes how denseners were successfully employed in moulds for the pro- duction of a cast-iron race wheel 11 ft. in dia. and a bevel pinion wheel 9 ft. in dia. They were used to prevent shrinkage cavities at the junctions of light and heavy sections of the castings.

Continuous Casting. T. W. Lippert. (Iron Age, 1940, vol. 145, Apr. 4, pp. 31–39; Apr. 11, pp. 44–47). The author reviews the methods of continuous casting, both successful and unsuccessful, which have been tried in the United States and other countries for the production of billets, rod and strip of both ferrous and non- ferrous metals with special reference to those of Bessemer and Hazelett. One of the processes was described in detail in a paper on continuous casting by E. R. Williams (*see* p. 10 A).

PRODUCTION OF STEEL

The Heat Supply to Open-Hearth Furnaces. I. Kazantsev. (Stal, 1939, No. 9, pp. 25–30). (In Russian). The author describes the design of a disc-type temperature testing device which enables the determination of the heat transfer in any direction in the melting zone of an open-hearth furnace to be made; from this the amount of heat absorbed by the charge can be calculated. It is concluded that in spite of the limited refractoriness of the furnace walls, full use is not being made of the heat-transfer capacity, the proper exploitation of which would more than double the furnace output. In addition to giving some experimental data, the author considers in detail the effect of the method and rate of charging on the melting time, as well as the effect of the intensity of the boil and the rate of heating up of the molten metal. Means of increasing the thermal capacity of an open-hearth furnace (*e.g.*, by the removal of resistances to flow in flues, by flame control and by heat insulation) are discussed. In this connection, reference is made to the formation of fine slag dust, which influences the wear of certain parts of the furnace. Slag pockets should remove dust less than 50 μ in dia.

The Design of Open-Hearth Furnaces for Increased Production. I. Semikin. (Stal, 1939, No. 9, pp. 15–19). (In Russian). Large capacity (300–350 ton) furnaces are capable of producing up to 1000 tons of steel in 8 hr. For this it is necessary to increase the heat supply during the charging period to 50–60 million cal. per hr. using forced draft at a pressure of 100–150 mm. of water. Utilisation of the heat of the flue gases for steam raising is possible. The furnace should be made gas-tight by a steel shell. Gas and air uptakes and slag pockets and regenerators should have individual walls. Spaces between slag pockets and regenerators should be ventilated. The author discusses more particularly, and with some reference to experimental data and works experience, the design of the bath and the volume of the furnace, methods of supporting the furnace structure, port design, slag pockets, regenerators, reversing valves and flues.

The Effectiveness of Increasing the Weight of the Charge of Open-Hearth Furnaces. Ya. Shneerov. (Stal, 1939, No. 9, pp. 34–40). (In Russian). Using a considerable amount of data from various Russian steelworks, the author, in discussing the increase in the output capacity of a furnace with increased weight of charge, comes to the conclusion that the former increases by 50–60% of

the increase in weight of the charge when using molten pig iron, and by 40% when using cold pig iron. The rational increase in the weight of the charge should have for its object the full utilisation of the thermal capacity of the furnace during the second period of the heat (melting and boiling). A graph shows how an increased charge results in a lower specific fuel consumption. For a given charge an increase in the heat supply has a definite optimum limit. Increased heat supply beyond that limit will be wasted unless it is accompanied by an increase in the weight of the charge with its resulting greater heat requirements during the second period of the heat. Factors limiting the rate of heat supply with a given charge are considered. The connections are traced between the increase in weight of the charge, the specific fuel consumption and the furnace life ; and some general reference is made to the effect on the furnace and on furnace design of the use of larger charges. The effect of a deeper bath on the quality of the steel is mentioned, but definite data on this point appear to be still lacking.

Manufacture of Basic Open-Hearth Steel. H. M. Griffith. (American Society for Metals : Canadian Metals and Metallurgical Industries, 1940, vol. 3, Mar., pp. 70–71, 89). The author outlines the processes of producing pig iron, basic and acid open-hearth steels, and rimming, killed and semi-killed steels. In conclusion he discusses the effects of additions of nickel, chromium, vanadium and molybdenum in the production of steel for forgings.

The Optimum Conditions for the Refining of Steel. P. Ivanov. (Stal, 1939, No. 9, pp. 23–25). (In Russian). The author discusses the effect of three factors which are considered to have a decisive influence on the quality of the steel produced, namely, the mean rate of elimination of the carbon, the duration of the boil and the nature of the carbon elimination curve. Depending on the conditions of melting, all these three factors should be given definite values. In addition, they should be placed in a definite relationship to the duration of the so-called " pure boiling," i.e., the period of boiling under normal non-frothing slags covering not less than two-thirds of the surface of the metal bath.

Essential Conditions of Open-Hearth Melting Determining the Production of Fine-Grained Carbon Steel. V. Mozharov. (Stal, 1939, No. 9, pp. 19–23). (In Russian). The greater part of the article consists of a summary of published information on methods of grain-size control with special reference to the effect of deoxidation. Certain conclusions regarding open-hearth melting practice, boiling, slag control, and preliminary and final deoxidation are deduced. With regard to deoxidation, some experimental results are given to show the effect of adding a certain proportion of the total quantity of aluminium in the ladle and the remainder in the mould on the impact strength at room and at low temperatures. The relative proportions of aluminium added appear

to depend to some extent on the state of the steel before tapping. The best results were obtained by adding 70–75% of the total aluminium to the ladle and the remaining 30–25% to the mould.

Means of Improving the Quality of Open-Hearth Steel. N. Dobrokhotov. (Stal, 1939, No. 9, pp. 12–14). (In Russian). Factors affecting the surface quality of open-hearth steel ingots are briefly discussed. An improvement in this respect can be achieved by raising the final temperature of the metal in the furnace, which of course raises the teeming temperature. The pouring rate must also be considered, particularly in the case of rimming steel, which can be teemed so as to fill the mould at the rate of 0·2 m. per min., while for killed steel a rate of 0·4 m. per min. is satisfactory. Silico-manganese as a deoxidiser is to be preferred to ferro-manganese and ferro-silicon added consecutively. If a mixture of the two is used, it should be preheated to avoid chilling the bath. Mould (as distinct from ladle) additions of aluminium (0·15 kg. per ton) are to be recommended and are claimed not to give rise to contamination. The use of floating hot-tops confers certain advantages. In acid open-hearth furnaces melting should be effected at a high temperature and with a deep bath. Before rolling, the ingots should be preheated to 1200–1300° C.

The Production of Rimming Steel. V. Kamenskiy. (Stal, 1939, No. 9, pp. 30–34). (In Russian). Cheaper rimming steel can be used satisfactorily in many cases instead of killed steel, and the former even offers definite advantages in some instances, *e.g.*, for deep-drawing. The causes of gas evolution in the mould are considered. Boiling during refining, and teeming must be controlled. The quality of the steel depends on the structure of the ingot and the distribution of blow-holes. Sufficient information on means of controlling the distribution of blow-holes is not available and the question needs further investigation. Melting and deoxidising practice for the production of rimming steel are discussed. Hard and fast rules for these cannot be laid down.

Equilibria in Liquid Iron with Carbon and Silicon. L. S. Darken. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1163 ; Metals Technology, 1940, vol. 7, Feb.). The author applies the law of mass action to the homogeneous equilibria of molten iron with carbon and silicon, assuming that the compounds Fe_3Si and Fe_3C are present in the melt, and he tries to bring his data into agreement with those obtained by other investigators for various equilibria of importance in steelmaking, *viz.*, the solubility of graphite in liquid iron and in iron-aluminium and iron-silicon melts ; the vapour pressure of the iron-carbon system at high temperatures and the carbon-monoxide/carbon-dioxide ratio in equilibrium with this system ; the heat of formation of iron carbide ; and the equilibrium between silicon and manganese in molten low-carbon steels and between the respective oxides in the

slag phase and the deoxidising characteristics of silicon. The consistency of the results of the author's calculations indicates that the use of the ordinary form of the law of mass action is justified when dealing with solutions in liquid iron, provided, however, that the formation of compounds is taken into account and that the silicon content of the melt is not higher than 15%.

Slag-Metal Relationships in the Basic Open-Hearth Furnace. K. L. Fetters and J. Chipman. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1164 ; Metals Technology, 1940, vol. 7, Feb.). In numerous diagrams and tables the authors present the results of a statistical analysis of the relationship existing between the compositions of the metal and the slag during the final stages of the basic open-hearth process just before deoxidation. They briefly explain the way in which they applied the method of statistical analysis to data compiled on 424 heats produced by eight different steelworks. The results obtained indicate the possibility of predicting the iron-oxide content of the metal at the time the heat is ready for deoxidation from other quantities that are more quickly determined by preliminary analysis, *viz.*, the carbon content of the metal or the basicity and the iron-oxide content of the slag.

Electrodeposition of Iron from Silicate Melts. W. Geller. (Zeitschrift für Elektrochemie, 1940, vol. 46, Apr., pp. 277–278). The authors studied the electrical conductivity of molten iron silicate and succeeded in depositing iron, which proves Körber and Oelsen's assumption that there is an electrolytic dissociation of molten iron silicate with the formation of iron ions (*see* Journ. I. and S.I., 1934, No. I., p. 489). The author's results are in agreement with those published by Sauerwald and Neuendorf in Zeitschrift für Elektrochemie, 1925, vol. 31, p. 643 and 1928, vol. 34, p. 199. (*See also* Journ. I. and S.I., 1929, No. I., p. 674).

Present Status of the Electric Arc Furnace in Industry. W. E. Moore. (Electrochemical Society, 1940, Apr., Preprint No. 27). The author reviews the development and present status of the electric arc furnace and states that the modern top-charge furnace with a roof that can be rapidly lifted, swung aside and replaced, is in competition with open-hearth furnaces for the production of ordinary as well as special steels. He quotes some operating data relating to a 12-ton furnace supplied from a 7500-kVA. sub-station ; this produced 198 tons of good-quality basic steel ingots per day with a current consumption of 680 kWh. per ton, and the time cycle from " power on " to " power off " was 2 hr. ; the ingots were made from cheap bulky scrap.

Electric Furnace Alloy Steels for Forgings. H. P. Rassbach. (Electrochemical Society, 1940, Apr., Preprint No. 29). The author compares the advantages and disadvantages of using basic- and acid-lined arc furnaces and basic- and acid-lined induction furnaces for the manufacture of alloy steels for forgings.

Largest Electric Furnace Installation in South Africa. (Iron and Coal Trades Review, 1940, vol. 140, Mar. 29, pp. 495–496 : Engineer, 1940, vol. 169, Apr. 5, pp. 333–334 : Engineering, 1940, vol. 149, Mar. 29, pp. 330–332 : Foundry Trade Journal, 1940, vol. 62, Apr. 4, pp. 251–252). A brief illustrated description is given of an 8-ton Birlec Lectromelt furnace, rated at 3600 kVA., recently installed at the works of the Chamber of Mines Steel Products, Ltd., Johannesburg. The furnace is used for melting down the steel scrap from the company's mines.

" Crusts " in the Lower Part of an Ingot. F. Grigor'ev. (Stal, 1939, No. 8, pp. 49–51). (In Russian). " Crusts " consisting of metal with about 0·1% lower carbon content and comparatively rich in oxide inclusions were detected in the lower parts of bottom-poured ingots. It is suggested that they are formed by the first portions of metal which rush into the mould in a fountain and then fall on the walls and bottom of the mould, forming on the latter a " pancake " which is broken up by the metal which follows, bits of it giving rise to " crusts." Investigations showed that " crusts " could not be satisfactorily eliminated by cropping the back ends of blooms and billets. Neither did various shapes and thicknesses of mould bottom have much effect on the formation of crusts, which, however, could be practically completely eliminated by raising the pouring temperature, particularly in the beginning.

REHEATING FURNACES

Mechanical Stoking of Reheating Furnaces. T. Holm. (Jern-kontorets Annaler, 1939, vol. 123, No. 12, pp. 570–583). (In Swedish). The author describes and discusses the design of several types of reheating furnaces for which mechanical stoking is em-ployed and points out numerous advantages of this system, among which is the facility with which automatic temperature and pressure regulation can be effected.

The Dependency of Scaling upon the Composition of the Gas Atmospheres, the Heating Period, the Temperature and the Gas Velocity. R. Bourggraff. (Stahl und Eisen, 1940, vol. 60, Feb. 15, pp. 129–137 ; Feb. 22, pp. 156–159). In view of the discrepancies in the literature on the extent to which the temperature and the composition of the products of combustion affect the scaling loss of rolling-mill products, the author undertook a detailed investigation of this problem by laboratory methods. Small blocks of steel $80 \times 20 \times 20$ mm. containing carbon 0.05%, manganese 0.41%, phosphorus 0.042% and sulphur 0.040% were tested in atmospheres classified in the following four groups : (a) A mixture of the inert gas nitrogen with one of the oxidising gases carbon dioxide, oxygen, steam and sulphur dioxide ; (b) a mixture of two oxidising gases ; (c) a mixture of an oxidising gas with a reducing gas ; and (d) blast-furnace gas, coke-oven gas and producer gas mixed with air in various proportions. The effect of the velocity of the gases upon the scaling loss was also studied. The results are presented with numerous graphs, and examples are given of calculations by which the results obtained with simple atmospheres can be applied to complex atmospheres. The physical and chemical properties of the scale are also discussed. A bibliography of 139 references is appended.

FORGING, STAMPING AND DRAWING

Instantaneous Forging Control. (Steel, 1940, vol. 106, Apr. 8, pp. 73–74). A description is given of a system of automatic temperature control installed on an oil-fired forging furnace. A potentiometer-recorder is used, and this actuates a solenoid-operated three-way pilot valve which, in turn, regulates the air pressure on the diaphragm of an oil-air proportioning valve governing the supply of oil to the burners.

Steel-Faced Cast-Iron Dies for Drop Hammer Work. J. H. Engel. (Iron Age, 1940, vol. 145, Mar. 21, pp. 46–48). The author describes the manufacture of dies for making aluminium-alloy drop-forgings for the aircraft industry. It has been found economical to line the cavity of the lower cast-iron die with 16–18 gauge cold-rolled or deep-drawing steel sheet and to face the upper die with soft lead.

Residual Tin in Steel. P. J. McKimm. (Steel, 1940, vol. 106, May 6, pp. 64–68 ; May 13, pp. 60–69). The author reports on a number of tests which were made to establish whether any relationship existed between the tin content of steel and its deep-drawing properties. Ingots containing different percentages of tin were prepared by charging tin-bearing scrap and by adding tin to the ladle and these were rolled into strip. In some cases samples from the ingot face showed 0·09% of tin and the core as much as 0·85%. On rolling out into strip it was noticed that the slabs containing the higher and lower percentages of tin rolled normally, but those with an intermediate tin content had developed a peculiar colour and rolled extremely " hard " ; this hardness was also observed in subsequent cold reduction. The fact that steel high in tin can be used for deep-drawing permits the use of tin-contaminated scrap which is a cheap raw material.

Reactive Wire Drawing in Practice. H. A. Stringfellow. (Wire and Wire Products, 1940, vol. 15, Mar., pp. 159, 169). The author presents some of the results obtained when drawing wire of 0·60% carbon steel on an experimental reactive wire-drawing machine. In reactive drawing a back-pull is applied, and with the particular machine used the ratio of the back-pull to the pull of the drawing block could be varied and the pressure on the die could be measured. The author came to the following conclusions : (1) Die pressures are reduced by 20–40% by reactive drawing and the reduction in pressure varies inversely, but not proportionally, with the amount of the reactive load ; (2) the die pressure is unaffected by the speed of drawing ; (3) the properties of reactively-drawn wire are different from those of wire drawn in the conventional manner, the properties

of the former depending upon the condition of the rod or wire prior to drawing and the amount of cold-work to which it is subjected during the process ; (4) it is probable that when reactive drawing is properly applied, a greater degree of reduction can be obtained without resorting to heat treatment ; and (5) the technique of re-active drawing provides a means not only of reducing the cost of production but also of improved control of the physical properties of the finished wire.

High-Strength 18/8 Stainless Steel Wire for Cables. F. Khimu-shin, S. Ratner and Z. Rudbakh. (Stal, 1939, No. 8, pp. 40–46). (In Russian). Earlier work and recommendations regarding the drawing, heat treatment, pickling, lubrication and polishing of stainless-steel wire are critically summarised. Regarding inter-mediate annealing, the authors point out that a " recovery " anneal at 820–850° C. is preferable to the high-temperature (925–955° C.) annealing which has been suggested. The lower temperature reduces scaling losses. The two steels used in the investigations were $EYa1$ and $EYa2$, containing carbon 0·10% and 0·19%, silicon 0·37% and 0·58%, chromium 17·65% and 17·35%, and nickel 8·92% and 9·40%, respectively. A very wide study was made of the effect of the wire-drawing and heat-treatment schedules on the properties of the wire obtained, which included the tensile strength, ductility, resistance to torsion, hardness and magnetic properties. The question of lubrication and, in conclusion, the tensile and fatigue strength of cables receive some mention. The best method of wire-drawing was found to be to use total drafts of 55–60% (individual drafts of 20–30%), except for the final draft, with inter-mediate anneals at 840–860° C. Before finish-drawing, the wire was quenched from 1100–1150° C., and the final drawing was effected with individual drafts of 10% and a total of 93–94% reduction. Wire produced in this way had a tensile strength of 240–260 kg. per sq. mm. and in general was equal to imported American wire. The above very large drafts and the resulting mechanical properties could be obtained only by using a zinc coating as a lubricant. The use of steel $EYa1$ with the lower carbon content was preferable. The zinc coating was removed by pickling in weak acid and the wire was polished by drawing.

ROLLING-MILL PRACTICE

Aspects of Iron and Steel Rolling. J. F. Whitfield. (Cleveland Institution of Engineers : Iron and Coal Trades Review, 1940, vol. 140, May 10, pp. 719–720 ; May 17, pp. 753–754). The author discusses the theory of hot-rolling with particular reference to some aspects of surface friction, the effect of temperature, torque, power requirements and bearings of different types.

Energy Consumption in Rolling with Smooth Rolls. A. Chekmarev. (Stal, 1939, No. 9, pp. 41–44). (In Russian). Mathematical expressions for the energy consumption in rolling suggested by different Russian authors are critically considered. The conclusion is arrived at that there is a fundamental difference between expressions for the energy consumption derived from a consideration of the speed of the rolls and those derived from a consideration of the speed of the metal. The figure given by expressions of the first type is greater than that derived from the other expressions by the amount of energy lost in the friction resulting from the slipping between the metal and the rolls. The author derives expressions for the work done against this friction due to slipping and the work done by the friction which is taken up by the metal.

Rolling of Sheet and Strip. G. Sachs. (Iron Age, 1940, vol. 145, Mar. 28, pp. 25–27, 108 ; Apr. 4, pp. 48–51). The author describes the different types of rolling mills for the hot- and cold-rolling of sheet and strip and explains some methods of calculating the stress-strain relationships involved in rolling.

Slivers in Cold Reduced Strip. P. J. McKimm. (Blast Furnace and Steel Plant, 1940, vol. 28, Mar., pp. 243–246, 252). The author discusses some possible causes of defects in cold-rolled strip. These defects, called " slivers," vary greatly in appearance. They are sometimes visible faint streaks and sometimes they can only be found by touch as minute sharp protrusions. The author found that the occurrence of these defects was related to the nature of the atmosphere in the reheating furnace used before rolling down the slab. His tests showed that when burning oil, the oxygen content of the furnace atmosphere should be below 3% and the ratio of the heating-up time to the soaking time should be as small as possible.

HEAT TREATMENT

Flame-Hardening Cast Iron. A. O. Day. (Steel, 1940, vol. 106, May 6, pp. 46–49). The author describes and illustrates the structures obtained by flame-hardening cast iron and presents two curves showing the hardness variations between the surface and the core as the depth increases in stages of 0·02 in. To achieve good results by flame-hardening, the iron should contain 0·60–0·80% of combined carbon.

Crankshaft Hardening. (Steel, 1940, vol. 106, Apr. 29, pp. 50–52, 78). A description is given of an automatic hardening machine for hardening the bearing surfaces of automobile engine crankshafts. The principle of oxy-acetylene flame-hardening is applied by revolving the shaft at 150–200 r.p.m. in a trough through the sides of which project four pairs of oxy-acetylene torches aligned so that each bearing surface is heated by two flames. There are also four water-quenching nozzles. The whole operation is automatically controlled by a reduction-gear-driven camshaft with sixteen cams ; these operate valves which turn on and off the supplies of gas and water at the correct predetermined time intervals. The output of the machine is twenty crankshafts per hour.

Automatic Control of Furnace Atmospheres. H. M. Webber. (Instruments, 1940, vol. 13, Mar., pp. 73—76). The author describes some of the plants used for the preparation of special atmospheres for annealing furnaces, giving flow diagrams as well as details of instruments used for recording the dew-point of gases and for controlling their volume and pressure.

Practical Annealing. E. G. de Coriolis. (Carnegie Institute of Technology : Blast-Furnace and Steel Plant, 1940, vol. 28, Mar., pp. 258–261 ; Apr., pp. 351–353, 362 : Heat Treating and Forging, 1940, vol. 26, Mar., pp. 141–146, 149). In this general discussion of annealing, the author considers the degrée of specialisation now achieved, and then describes the effect of nitrogen, oxygen, carbon dioxide, carbon monoxide, hydrogen, water vapour and methane upon a steel surface in an annealing furnace. He next describes the principles employed in generating annealing-furnace atmospheres by the partial combustion of fuel gases, by cracking and by burning charcoal in an enclosed retort. In the concluding part of his paper he deals with various methods of controlling the temperature of annealing furnaces and the heating and cooling rates of the charge.

Stress Relief by Electric-Furnace Treatment. M. V. Healey and F. H. Miller. (General Electric Review, 1940, vol. 43, Apr.,

pp. 170–173). After explaining the principles of stress-relief heat treatment for castings, the authors describe and illustrate a 2000-kW. electric furnace at the Schenectady Works of the General Electric Co. This furnace can take charges of 80–100 tons measuring up to 27 ft. × 13 ft. × 17 ft. The usual heating schedule consists of heating to 600–650° C. in 12 hr., holding this temperature for 6 hr. and cooling to 100° C. in 22 hr. Forced cooling equipment has been installed which has resulted in the original cooling time of 80 hr. being reduced to that stated above.

Normalising and Stress-Relief Annealing Welded Joints. O. Schmidt and E. Jöllenbeck. (Elektroschweissung, 1940, vol. 11, Apr., pp. 57–62). The authors discuss the purpose of annealing welded joints, temperature schedules suitable for various applications, and the advantages and disadvantages of normalising and stress-relief annealing. In this paper the authors define " normalising " as annealing at a temperature above the Ac_3 point, in the course of which the structure undergoes a complete transformation, and " stress-relief annealing " as a heat treatment at below the Ac_1 point during which no transformation takes place.

Stripsheet Annealing. (Steel, 1940, vol. 106, Apr. 15, pp. 48–49, 72). An illustrated description is given of the annealing equipment of the Otis Steel Co., Cleveland, Ohio. This consists of eighteen bell-shaped annealing covers heated by vertical radiant tubes, the fuel being high-pressure natural gas. There are thirty bases in the annealing department of the hot mill, and any furnace will fit over any base. An efficient system of temperature recording and control is installed by which the thermocouples and controls of a furnace can be plugged in to the central control panel immediately a furnace is lowered on to a fresh base.

Heat Treating and Forging in a Typical Railroad Shop. C. Cleveland. (Heat Treating and Forging, 1940, vol. 26, Feb., pp. 61–64, 67). The author gives an illustrated description of the new heat-treatment and forging shop of the Norfolk and Western Railway at Roanoke, U.S.A.

The Heat Treatment of Tool Steels. (Machinery, 1940, vol. 56, May 23, pp. 231–233). A number of heating and cooling schedules are presented for the satisfactory heat treatment of carbon steel tools containing carbon within the following limits : (a) 0·65–0·80% ; (b) 0·80–0·95% ; (c) 0·95–1·10% ; and (d) over 1·10%.

Heat Treating Implement Parts. J. P. Wilson. (Industrial Heating, 1940, vol. 7, Feb., pp. 114–116, 128). The author presents an illustrated description of the hardening and tempering furnaces recently installed at Philadelphia by S. L. Allen Co., manufacturers of farm and garden tool equipment.

The Stepped Quenching of Low-Tungsten Substitutes for High-Speed Steel. A. Gorbunov and Ya. Dovgalevskiy. (Stal, 1939, No. 8, pp. 47–49). (In Russian). The steels investigated were *EI*173 (carbon 1·1%, chromium 9·2%, tungsten 2·37%, vanadium

0·81%) and *EI*184 (carbon 0·89%, silicon 0·53%, chromium 7·41%, tungsten 4·39%, vanadium 1·32%). Most of the experiments were made on the former steel. The fully annealed specimens of this steel were heated at 1200° C. for 5 min., then transferred to a lead bath at a temperature of 550–700° C., held for various periods of from 10 to 180 min. and then cooled in still air. Tests on heat-treated speci- mens included Rockwell hardness measurements and measurements of the magnetic saturation and the coercive force. Subsequently the effect of repeated tempering (1 hr. periods in a lead bath at 550° C.) on the step-quenched specimens was examined. A study was also made of " tempering " step-quenched specimens at −182° C. followed by ageing at 100° C. It was found that by suitable stepped quenching with subsequent triple tempering it was possible to decompose the residual austenite in these steels almost completely and thereby raise the hardness to Rockwell C 64–65. On ageing at 100° C. the austenite decomposed less completely (although more so than after ordinary quenching and triple tempering). A maximum hardness of about Rockwell C 66 was obtained by quenching from 1200° C. in a bath at 550–600° C., holding for 10–60 min., then tempering in liquid nitrogen and finally ageing at 100° C. for 1 hr.

Hardenability and Quenching. M. A. Grossmann and M. Asimow. (Iron Age, 1940, vol. 145, Apr. 25, pp. 25–29 ; May 2, pp. 39–45). The author reproduces and explains the use of a chart the purpose of which is to provide a means of standardising the severity of quenching and of ascertaining the degree of quenching to which a steel has been subjected. The chart is based on the deter- mination of the ratio Du/D, where Du is the diameter of the un- hardened core of a test-piece after quenching, and D is the diameter of the bar. The above chart and a brief explanation of its use are reproduced as a data sheet in Metal Progress, 1940, vol. 37, Apr., p. 427.

Proper Quench Tanks Save Time and Energy. (Iron Age, 1940, vol. 145, May 2, p. 38). Brief descriptious and drawings are pre- sented showing the design of small and large quenching tanks for small tool and die shops and for production heat-treatment depart- ments.

Spheroidizing. (Steel, 1940, vol. 106, Apr. 15, pp. 64–66). A description is given of a heat-treatment installation for the spheroidising of high-carbon and alloy steel rod, the object of which is to make the stock sufficiently ductile for the cold-heading opera- tion in the manufacture of bolts.

WELDING AND CUTTING

Resistance Welding—The What, Why and How. L. D. Jennings. (Iron Age, 1940, vol. 145, May 9, pp. 38–43). The author explains the principles of electrical resistance welding and describes some of the types of resistance-welding machines. He also presents tables showing the correct mechanical pressure on the electrodes, the welding current and duration of application necessary for the spot welding of different thicknesses of steel and non-ferrous metal sheet.

British Standard Specification for Metal Arc Welding in Mild Steel as Applied to General Building Construction. (British Standards Institution, No. 538–1940). This specification contains the detail of butt and fillet welds in mild steel for general building purposes and constitutes a revision of British Standard Specification No. 538—1934.

Hard Surfacing. M. L. Begeman. (Canadian Metals and Metallurgical Industries, 1940, vol. 3, Feb., pp. 44–49, 54 ; Mar., pp. 72–76). The author reviews recent literature on the hard surfacing of materials by the deposition, by gas or electric welding, of a layer of hard ferrous or non-ferrous alloy.

Spot Welding of Automobile Grade Mild Steel. W. F. Hess and R. A. Wyant. (Society of Automotive Engineers : Welding Industry, 1940, vol. 8, Feb., pp. 10–12 ; Mar., pp. 44–45). The authors discuss the results obtained in the Rensselaer Polytechnic Institute Welding Laboratory during investigations of the properties of spot welds in deep-drawing steel 0·036 in. in thickness containing 0·05% of carbon. Some of the results have been reported previously (*see* Journ. I. and S.I., 1940, No. I., p. 149 A). They describe briefly the testing apparatus available and consider how the time of current-flow, the shape and mechanical pressure of the electrodes, the amperage and the grain size of the steel affected the properties of the welds produced.

Welding of Rail-Ends and Joints of Crane Runways. W. Dudley. (Iron and Steel Engineer, 1940, vol. 17, Apr., pp. 58–65). The author gives details of the experience gained at a steelworks in 1939 in the welding of crane runway rails as a means of building up battered ends and constructing long continuous lengths. He compares the costs of the oxy-acetylene, electric and thermit welded joints, and states that, generally speaking, defective joints in crane runways can be successfully and economically repaired by welding, provided that : (*a*) The defects are limited to wear at the ends

(*b*) proper welding procedure and suitable electrodes are used ; and (*c*) at least one year's useful life can be expected from the railhead.

Repair by Welding of a Cast-Steel Hydraulic Cylinder. (En-gineering, 1940, vol. 149, May 10, pp. 475–477). A detailed illus-trated description is given of a repair carried out by electric welding on a cracked cast-steel cylinder of a 2000-ton cable-sheathing press. Over 3000 electrodes were used, which represented the deposition of over 5 cwt. of metal.

Some Points in the Design and Inspection of Pressure Plant. A. H. Goodger. (Proceedings of the Society of Chemical Industry, Chemical Engineering Group, 1939, vol. 21, pp. 98–104). After reviewing the more important heat- and pressure-resisting alloys used for chemical plant, the author briefly discusses the phenomena of surface and intergranular corrosion, of corrosion-fatigue, and of embrittlement and scaling at high temperatures. The main part of the paper deals with the welding of chemical plant, which is considered under the following headings : Welding as an adjunct to design and construction ; jacketed pans ; flanges ; welded stays ; one-sided welds and corrosion fatigue ; seal welding ; welding of stainless steel ; welding of clad metals ; heat treatment of welded vessels ; and inspection of welded plant.

PROPERTIES AND TESTS

Plastic Flow in Metals. H. W. Swift. (Sheffield Metallurgical Association : Metal Industry, 1940, vol. 56, Feb. 2, pp. 127–130 ; Feb. 9, pp. 149–152 ; Feb. 16, pp. 173–175). In this review of the present state of knowledge regarding the plastic flow of mild steel, the author points out that stress-strain relationship under compound stress requires further comprehensive and elaborate experimental study. He discusses the theories governing plastic flow in a single crystal and in crystalline aggregates and the theories which have been advanced in explanation of strain-hardening ; among the latter are the mosaic and dislocation theories and that of Beilby.

Toughness—Particularly of Toolsteel. R. S. Rose. (Metal Progress, 1940, vol. 37, Apr., pp. 407–411). In discussing the toughness of steel and how this property may be measured, the author emphasises the importance of the relation between the shear strength at which deformation commences and the cohesive strength at which fracture occurs. He deals next with the interpretation of tensile and impact tests, showing that toughness cannot be evaluated from any one test. In conclusion he points out why toughness is adversely affected by internal stresses, cold-work, coarse-grained structure, high hardness and segregation, and why it can be favourably affected by the addition of suitable alloying elements.

Significance of Tension Test. J. M. Lessells. (Mechanical Engineering, 1940, vol. 62, Apr., pp. 311–314). The author makes some observations on the application of tensile test results to design with the object of preparing the way for the discussion which followed the presentation of papers on " The Significance of the Tensile Test in Relation to Design," at the annual meeting of the American Society for Testing Materials at Atlantic City in June, 1940.

The Evaluation of the Ductility of Metals in Bending. M. P. Markovets. (Zavodskaya Laboratoriya, 1939, No. 10–11, pp. 1155–1162). (In Russian). A preliminary discussion, illustrated by some experimental results, leads the author to the conclusion that it is the necking, or reduction-in-area, characteristic that determines the behaviour of a metal in bending, and not the elongation, as the latter is not a single property but is made up (e.g., as measured in the tensile test) of localised and general elongation, and it is thus possible that a metal with a high elongation will fail more readily than a metal with a lower elongation.

In bending round a fixed radius the outer fibres are stretched uniformly with a maximum elongation corresponding with the reduction of area in a tensile test. The minimum radius (r) of curvature in bending is given by

$$r = \frac{1 - 2\psi}{2} \times h$$

where ψ is the reduction in area in the tensile test and h is the height of the material in the bending plane. A method of measuring the reduction in area in the case of flat thin test-pieces is described. A considerable amount of experimental data obtained for steels and aluminium and magnesium alloys is quoted and is found to substantiate the accuracy of the limiting radii of curvature in bending calculated from the above expression, as compared with actual measurements.

Measurement of Impact Strains by a Carbon-Strip Extensometer. R. Fanning and W. V. Bassett. (Journal of Applied Mechanics, 1940, vol. 7, Mar., pp. A-24–A-28). The authors describe some experiments using an apparatus incorporating a cathode-ray oscillograph by means of which accurate strain-time curves for points at various distances along a suspended steel bar, subjected to an impact at one end, were obtained. The authors also examined the theory of strain waves in long bars striking end to end and found that there was good agreement between the theoretical and the experimental results.

A Work-Brittleness Test for Steel. H. W. Graham and H. K. Work. (Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 571–580). The authors describe a simple test which is intended to provide information on the changes in the embrittlement of steel subjected to different degrees of cold-work. It consists essentially of drawing a tapered specimen through a die, notching it at points representing various increments of cold-work, and breaking it in an Izod machine. From the data obtained a curve is constructed by plotting the impact values against the percentage reduction in area.

Stress, Strain and Structural Damage. H. F. Moore. (Edgar Marburg Lecture : Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 549–570). The author considers the fundamental conceptions of stressed materials, and gives examples of four types of structural damage due to mechanical causes, namely, elastic deformation, damage by inelastic action, fracture and damage by creep. He then describes methods of testing the ability of materials to resist these forms of damage.

Introductory Study of Fatigue in Steels. A. F. Cotton, F. M. Mathews and N. C. Fraser. (Metallurgical and Engineering Society of Port Kembla : Heat Treating and Forging, 1940, vol. 26, Mar., pp. 130–135). In the first part of their paper the authors define and discuss some fundamental factors governing the fatigue of metals. In the second part they describe several examples of

fatigue failure, and in the concluding part they describe some examples of corrosion fatigue, stating that this is dependent on three properties of steel in the following order of importance : (1) Electrolytic potential ; (2) notch sensitivity ; and (3) fatigue limit.

Machine for Determining the Bending Fatigue Strength of Flat Test-Pieces. S. E. Graf. (Zavodskaya Laboratoriya, 1939, No. 10–11, pp. 1163–1167). (In Russian). Analytical calculations relative to the design of the machine described confirm the satisfactory results which have been obtained with it. It is possible to apply a permanent initial load to the test-piece and thus subject it to an unsymmetrical stress cycle. Stresses in the test-piece due to inertia forces did not exceed 3% and were taken into account in calibrating the machine which was designed for the simultaneous testing of five specimens.

Plastic Yielding and Fatigue of Ductile Metals. A Criterion and its Application. R. W. Bailey. (Proceedings of the Institution of Mechanical Engineers, 1940, vol. 143, May, pp. 101–107). In this mathematical treatise the author suggests a criterion of the yielding of a ductile metal which embraces the several well-known criteria as special cases. The proposed criterion, which is based upon a hypothesis of surface anistropy of an otherwise isotropic material, is considered to be applicable in character to the fatigue of a ductile metal, and it is applied to derive, from direct and shear-stress fatigue test results, limiting fatigue stresses for any combination of shear stress and direct stress in phase.

Nickel-Containing Permanent Magnet Steels. M. Yamaguchi. (Japan Nickel Information Bureau, 1940, Technical Information B-13). In this comprehensive review of the development and properties of the nickel-bearing magnet steels the author first surveys the history of the development of magnet steels. In the second part he discusses the properties of : (*a*) Nickel-aluminium-iron alloys ; (*b*) nickel-cobalt-titanium alloys ; and (*c*) copper-nickel-iron alloys. In the third and concluding part he describes the manufacture and industrial applications of modern permanent magnet steels.

The Use of Modern Steels for Permanent Magnets. A. Th. van Urk. (Philips Technical Review, 1940, vol. 5, Feb., pp. 29–35). In order to obtain a certain magnetic field strength in a given air gap using as small a magnet as possible, the magnet must be so designed that the product of the induction and field strength in the interior of the magnet steel is as large as possible. In this paper the author explains this concept and shows how a magnet should be designed in order to use a given kind of magnet steel to the best advantage.

Iron-Nickel-Aluminium Alloys with Additions of Cobalt and Copper. B. Livshits and L. Kontorovich. (Stal, 1939, No. 8, pp. 26–30). (In Russian). The object of the investigation here de-

scribed was to study the effect of additions of both cobalt and copper on the magnetic properties of Mishima alloy and the possibility of obtaining a high residual induction with a sufficiently high coercive force. The approximate amounts of alloying elements in the three types of metals studied were :

	Ni. %.	Al. %.	Cu. %.	Co. %.
(1)	22	11	6	0–12
(2)	17	11	6	0–12
(3)	22	11	6	6

the balance being iron. The relationship of the magnetic properties to the composition and to the casting conditions (*i.e.*, whether chill-or sand-cast) were also examined. It was found that the addition of up to 12% of cobalt to an alloy of type (2) appreciably increased the magnetising force (H) and the product of the magnetic induction (B) and (H); the magnetic induction, however, slightly decreased. The alloy containing 12% of cobalt is of practical value, because the product of B and H is high as compared with that of 28/11 nickel-aluminium steel and of Alnico. This alloy, which is considered to be the best among those studied, has a coercive force of 580–740, a remanence of 5420–6200, and $B \times H$ of 360–400 depending on the casting conditions. In alloys of type (1) the addition of up to 12% of cobalt increases the magnetising force and the product $B \times H$; the maximum magnetic induction is obtained with 6% of cobalt for small sections. An increase in the nickel content from 17% to 22% in an alloy of small section containing cobalt 12%, aluminium 11% and copper 6%, increases H and lowers B, the product $B \times H$ remaining constant. A similar increase of the nickel content in an alloy containing cobalt 6%, aluminium 11% and copper 6% increases H and the product $B \times H$, and slightly reduces B. Chill-cast Alnico in sections of 12×12 mm. and 20×20 mm. is superior to the 28/11 nickel-aluminium steel, whereas sand-cast Alnico in sections of 30×30 mm. is inferior to the 28/11 steel. The addition of copper to Alnico has no beneficial results.

Notching—Its Effect on Coarse and Fine Crystalline Materials at Low and Elevated Temperatures. G. Welter. (Metallurgia, 1940, vol. 21, Apr., pp. 179–186). An investigation on the plastic behaviour of Armco iron, zinc, an aluminium alloy and brass under limited and free deformation is described. The dependence of the resistance to deformation and deformation capacity on notches, temperature and crystalline structure is discussed in the light of the results of tests, and the differences in tensile strength of individual materials are determined.

Factors Affecting Notched-Bar Impact Tests on Steel at Low Temperatures. W. Crafts and J. J. Egan. (Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 659–671). In order to determine the reasons for lack of correlation between different makes of Charpy and Izod impact testing machines in

tests at low temperatures, the authors carried out a survey to evaluate some of the variables which may be the cause of these differences. Izod and Charpy tests were carried out at low temperatures on a machine in which the initial energy and velocity of the blow could be varied independently. The radius and depth of the notch were also investigated in order to estimate the effect of the degree of accuracy of the dimensions of the specimen. The effect of the length of the cantilever arm of an Izod machine was also studied. The results indicated a general, but not extremely accurate, correlation between different makes of machines and the authors recommend a conservative use of the test for specification purposes.

Sub-Size Charpy Relationships at Sub-Zero Temperatures. H. Habart and W. J. Herge. (Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 649–658). The authors report on a series of Charpy impact tests made on four carbon and four alloy steels at temperatures ranging from $+ 70°$ F. to $- 150°$ F. using standard specimens 1 cm. $\times$ 1 cm. in section and others of smaller section. In general, ferritic steels lost impact resistance, as measured on standard and two-thirds size specimens when the testing temperature was decreased. One-half size specimens also lost impact resistance, but not in the same marked degree as did the larger specimens. The smaller specimens used had an almost constant impact resistance throughout the above temperature range. Austenitic 18/8 stainless-steel specimens showed increasing impact resistance with decreasing temperature.

Résumé of Round-Table Discussion on Effect of Sub-Atmospheric Temperatures on the Properties of Metals. (Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 637–641). This is a summary prepared by F. B. Foley of an open discussion on the properties of metals at low temperatures which followed the presentation of two papers at the annual meeting of the A.S.T.M. in June, 1939. The two papers were : " Factors Affecting Notched-Bar Impact Tests on Steel at Low Temperatures," and " Sub-Size Charpy Relationships at Sub-Zero Temperatures " (*see* preceding abstracts).

Diffusion of Hydrogen from Water Through Steel. F. J. Norton. (Journal of Applied Physics, 1940, vol. 11, Apr., pp. 262–267). The author reports on some experiments undertaken to determine the rate of diffusion of hydrogen through steel. For this purpose wireless valves with a shell of steel instead of glass were used, and these were dipped in water at $25°$ C. for various periods of time. They were then taken out and the grid current was measured. The strength of this current was a measure of the rate of ionisation. It was found that the steel surface of the valve, when cleaned by sand-blasting, was penetrated by hydrogen at the rate of 0·13 micron per hr. when immersed in water at $25°$ C. There was no diffusion of hydrogen when the valve was surrounded by water

vapour alone. Some results obtained with tin and copper-coated steel valves are also given.

Influence of Ladle Additions on the Properties of Cast Iron. E. Piwowarsky. (Foundry Trade Journal, 1940, vol. 62, May 2, pp. 325–327 ; May 9, pp. 350, 352 ; May 16, pp. 365–367). This is an abridged English translation of an article which appeared in Giesserei, 1940, vol. 27, Jan. 20, pp. 21–30 (*see* Journ. I. and S.I., 1940, No. I., p. 258 A).

Nickel Alloy Cast Iron. W. G. Wright. (Metals Treatment Society of New South Wales : Australasian Engineer, 1940, vol. 40, Apr. 8, pp. 15–17, 49–52). The author surveys the development of nickel cast irons and the properties of many of these cast irons which are now available for special applications.

The Quality of Steel and Steels of Quality. A. Portevin. (Revue de Métallurgie, Mémoires, 1940, vol. 37, Feb., pp. 37–47 ; Mar., pp. 61–70). The author discusses the many characteristics of steel and shows how difficult it is to attempt a classification on the basis of any one type of properties because of their interrelationship. The types of characteristics dealt with are : (*a*) Chemical composition ; (*b*) mechanical properties ; (*c*) forgeability and machinability ; (*d*) resistance to wear ; (*e*) inclusions ; and (*f*) structure.

How Alloying Elements Affect High Alloy Steels. P. Payson. (Iron Age, 1940, vol. 145, Apr. 18, pp. 31–35 ; Apr. 25, pp. 35–40). The author presents a summary on the influence of alloying elements on the properties of steel and shows how variations in the properties of these steels can be controlled to an appreciable extent. His summary is mainly devoted to the effect of additions of manganese, nickel, cobalt, tungsten, molybdenum and chromium.

Cast Chromium Steel. K. Roesch. (Iron and Steel, 1940, vol. 13, May, pp. 273–276). This is an abridged English translation of an article which appeared in Giesserei, 1939, vol. 26, July 14, pp. 357–360, in which the author discussed the wide range of properties which can be imparted to steel by the addition of different percentages of chromium. (*See* Journ. I. and S.I., 1939, No. II., p. 295 A).

" 18 and 8 " and Related Stainless Steels. W. M. Mitchell. (Metals and Alloys, 1940, vol. 11, Jan., pp. 14–18 ; Feb., pp. 60–64 ; Mar., pp. 88–93 ; Apr., pp. 119–122). The author discusses the physical and mechanical properties of the stainless steels in the range 16–25% of chromium and 6–20% of nickel, quoting much of the data published by Flader in his paper on " Stainless Steel in Aircraft Construction " (*see* Journ. I. and S.I., 1935, No. I., p. 515 A).

Stainless Steels for Use in Chemical Equipment. H. L. Maxwell. (Transactions of the American Institute of Chemical Engineers, 1939, vol. 35, pp. 159–167). After stating that stainless steel plates and commercial shapes with an approximate total value of twenty million dollars were supplied to fabricators of chemical process equipment in the United States in 1937, the author discusses the

properties, advantages and limitations of the several varieties of stainless steels with a view to presenting information which will assist in the selection of a material for a particular application. He presents a table of thirteen types selected from the American Iron and Steel Institute list which gives their chemical composition, mechanical properties and basis prices in July, 1938.

Tubes for Oil Heaters ; Titanium or Columbium in 5% Cr–Mo–Si Steel. H. Habart. (Metal Progress, 1940, vol. 37, Apr., pp. 401–405). The author discusses the results of an investigation of the properties of two special alloy steels and their suitability for the manufacture of oil-heater tubes. Both alloys contained about 5% of chromium, 1% of silicon and 0·5% of molybdenum ; one heat contained 0·39% of titanium and the other 0·50% of niobium. The properties investigated were the oxidation resistance, hardenability on cooling in air, resistance to grain growth, tensile strength and impact strength. The results showed that both materials had good oxidation-resistance at temperatures up to 1600° F., did not harden when cooled in air from temperatures up to 1700° F., were not subject to grain growth on reheating up to 2000° F., responded to ordinary annealing treatments, and possessed high impact strength. After manufacture into seamless tubes both steels had high ductility and good manipulating properties.

Effect of Phosphorus in 5 Per Cent. Cr, 0·50 Mo Steel. H. D. Newell and Z. E. Olzak. (Metals and Alloys, 1940, vol. 11, Apr., pp. 106–111). The authors report on the results of some tests carried out to ascertain the effects of adding phosphorus on the properties of steel containing about 0·10% of carbon, 5% of chromium and 0·50% of molybdenum. It was found that with the addition of up to about 0·20% of phosphorus the hardness, the limit of proportionality, the yield point and the tensile strength were all raised without seriously affecting the ductility. This improvement was also noted when the comparative tests were made at high temperatures. There was a slight decline in the impact strength with increasing phosphorus content, but this was not serious until the phosphorus exceeded 0·20%.

Steel Aircraft. E. J. W. Ragsdale. (Steel, 1940, vol. 106, May 6, pp. 70–72, 81). The author explains why it is possible to use thin plates and sections of stainless steel in the construction of aircraft wings.

Modern Methods of Mechanical Testing. W. E. Bardgett. (Journal of the West of Scotland Iron and Steel Institute, 1940, vol. 47, Jan., pp. 47–66). A description is given of the equipment used in the Central Research Department of the United Steel Companies, Ltd., for measuring damping, creep, wear and fatigue. The methods of testing are explained and a selection of test results, illustrative of the type of data obtainable, is given with comments on the results.

METALLOGRAPHY AND CONSTITUTION

Fine Focus Radiography—Gamma Rays. G. E. Doan and M. B. Vordahl. (Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 741–747). The authors describe an investigation which had the object of determining the smallest dimension of an internal crack in a metal object revealed under radiographic conditions. Using a bulb of radon with an initial strength of 45·6 millicuries and an inside diameter of about $\frac{1}{16}$ in., the authors found it possible to detect cracks 0·001 in. wide in blocks of steel 1 in. thick. Cracks 0·002, 0·003 and 0·005 in. wide could be detected in blocks 2, 3 and 4 in. thick, respectively. Each crack was $\frac{1}{4}$ in. in depth. In some cases the distance from source to specimen was reduced to as little as 1 in. without lessening the detectability; this enabled the exposure time to be reduced considerably.

Methods of Characterising Grades of Cast Iron According to their Microstructure. V. E. Kuksinskaya, V. N. Tyulenev and M. D. Chaykovskiy. (Zavodskaya Laboratoriya, 1939, No. 10–11, pp. 1138–1139). (In Russian). The authors suggest classifying cast iron by awarding marks for the graphite, pearlite, phosphide eutectic and ferrite. Marks for the graphite are based on the length of the graphite flakes and are determined by reference to a series of standard micrographs which are reproduced. Marks for the pearlite are awarded on the basis of the area it occupies and the size of its lamellæ. The phosphide eutectic and ferrite contents are estimated on an area basis only. The marks awarded to the above constituents are added up and the cast iron is classified in accordance with the total. This total shows some relation to the mechanical properties of grey cast irons.

Welding Metallurgy. Part III. Crystals. Part IV. How Crystals Grow from Other Crystals. O. H. Henry and G. E. Claussen. (Welding Journal, 1940, vol. 19, Mar., pp. 181–184; Apr., pp. 285–287). In Parts III. and IV. of this series (*see* Journ. I. and S.I., 1940, No. I., p. 294 A) the authors explain the terms electron, nucleus and crystal and the factors affecting the growth of crystals.

The Grain Size of Steel. J. R. Vilella. (Mechanical Engineering, 1940, vol. 62, Apr., pp. 293–307). After a brief outline of the fundamental principles governing the formation of ferrite, cementite and austenite, the author explains in simple terms the most important facts pertaining to the grain size of steel, and the methods of controlling and measuring the grain size.

The Nature of Non-Metallic Inclusions in Copper Steel and Chromium-Copper Steel. N. Leve and M. Shapiro. (Stal, 1939, No. 8, pp. 30–36). (In Russian). The authors describe an electrolytic method of separating non-metallic inclusions from ten alloy steels, three of which contained 0·18–0·78% of copper and the remainder 0·40–0·64% of chromium and 0·41–0·70% of copper. The non-metallic inclusions were transferred to a beaker containing distilled water and were separated roughly from the carbides present by stirring, subsequent complete separation being effected by a magnetic process. The non-metallic inclusions were examined under the microscope and some were also subjected to chemical micro-analysis. The authors also describe the various types of inclusions encountered and illustrate them with micrographs. They summarise the properties of the inclusions in a table which gives the type, shape, colour and birefringence, refractive index, solubility in chemical reagents and number of the inclusions.

Crystal Orientation in Silicon-Iron Sheet. J. T. Burwell. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1178 ; Metals Technology, 1940, vol. 7, Feb.). The author has made an X-ray study of 3·1% silicon iron strip, which had been hot-rolled and then subjected to cold-reduction in two stages followed by recrystallisation. The results, presented in the form of a pole figure, indicate that the component crystals are oriented with a (110) plane in the rolling plane and a [001] axis in the rolling direction.

The Brittle Phase in High Chromium Steels. J. H. G. Monypenny. (Metallurgia, 1940, vol. 21, Mar., pp. 143–148). The author reviews the literature dealing with the hard, brittle and non-magnetic constituent of certain high-chromium alloys which was discovered by Bain and Griffiths (*see* Journ. I. and S.I., 1927, No. I., p. 963), and is known as the σ-phase. He considers in particular a recent investigation by Schafmeister and Ergang on iron-chromium-nickel alloys containing this σ-phase and stresses the practical importance of their results. (*See* Journ. I. and S.I., 1939, No. I., p. 307 A).

The Systems MnO–TiO$_2$ and MnO–FeO–TiO$_2$. J. Grieve and J. White. (Journal of the Royal Technical College, Glasgow, 1940, vol. 4, Jan., pp. 660–670). The thermal equilibrium diagrams of the systems MnO-TiO$_2$ and MnO-FeO-TiO$_2$ have been determined by methods previously described. In the former system two compounds occur, MnO.TiO$_2$ and 2MnO.TiO$_2$, the former of which melts incongruently. In the ternary system there is complete solid solubility between MnO.TiO$_2$ and FeO.TiO$_2$ and between 2MnO.TiO$_2$ and 2FeO.TiO$_2$. A third solid solution series is made up by MnO and FeO, which are partly soluble in each other. Relationships within the system, which are considerably influenced by this solid solution formation, are indicated by diagrams showing the form of the liquidus surface and the phase distribution. Micrographs of representative melts are shown.

CORROSION OF IRON AND STEEL

Electrolytic Corrosion of Ship Structures. J. H. Paterson. (Institution of Engineers and Shipbuilders in Scotland : Metallurgia, 1940, vol. 21, Apr., pp. 197–200). The author explains the causes of local corrosion phenomena observed in ship structures by reference to the mechanism of electrolytic corrosion. This paper appeared previously in Iron and Coal Trades Review, 1940, vol. 140, Apr. 12, pp. 573–574 (*see* p. 38 A).

Influence of Chromium on the Oxidation Resistance of Cast Iron. C. O. Burgess. (Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 604–622). The primary object of the present investigation was to determine the effect of various chromium contents on the oxidation-resistance of cast iron. Eleven cast irons containing 0–25% of chromium were employed, and, during 360-hr. exposure periods, were heated and cooled from test temperatures of 700°, 800°, 900° and 1000° C. A special technique was employed to ensure comparable conditions and accurate determinations of gains in weight. Data so obtained definitely indicate the percentage of chromium necessary at each temperature level to limit the total oxidation of cast iron. The progressive weight-gain curves at 800° and 900° C. establish the chromium content required to produce an adherent scale at these two temperature levels. Low-carbon control specimens indicated that carbon content has relatively little effect on oxidation resistance. The rôle of chromium in inhibiting oxidation was clearly brought out by the metallographic examination. The penetration of an oxidation constituent, provisionally designated as metal-oxide, beneath the metallic surface of cast irons low in chromium was noted, and is believed to shed some light on the little-understood phenomenon of growth.

Some New Developments in Corrosion Resistant Steel. G. F. Landgraf. (Electrochemical Society, 1940, Apr., Preprint No. 30). The author discusses the results of recent research work at the Massachusetts Institute of Technology, which had the object of improving the resistance of stainless steels to hydrochloric acid and chloride salt solutions. He refers in particular to the corrosion-resistance properties of silver-bearing 18/8 stainless steel.

Nickel-Molybdenum-Iron and Related Alloys—Their Physical and Corrosion-Resistant Properties. F. T. McCurdy. (Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 698–708). The author presents the results of tests carried out at

the Union Carbide and Carbon Research Laboratories with the object of discovering alloys capable of resisting acid attack, particularly by hydrochloric and sulphuric acids. Four nickel-base alloys were developed, which are referred to as A, B, C and D. Alloy A contained iron 20%, molybdenum 20% and nickel 60%, and it withstood the attack of hydrochloric acid in all concentrations at temperatures up to 70° C., and of 50% sulphuric acid up to boiling point, but it was not resistant to oxidising agents. Alloy B contained iron 5%, molybdenum 30% and nickel 65% and was remarkable for its high corrosion resistance in hydrochloric acid of all concentrations and at all temperatures up to the boiling point ; this alloy can be made into castings, forgings, wire, plate, sheet and hot-rolled bars ; it is machinable and can be welded without loss of corrosion resistance. Alloy C was developed to resist the attack of nitric acid, wet chlorine and other oxidising agents ; it is similar to A, but chromium was substituted for part of the iron and a little tungsten was included. Alloy D is a nickel alloy containing approximately silicon 10%, copper 3% and a little aluminium, and it makes strong, tough castings which are fully resistant to sulphuric acid.

ANALYSIS

Modern Analysis in the Foundry. G. W. Zabel and J. Schuch. (Iron Age, 1940, vol. 145, May 2, pp. 31–37). The authors describe the apparatus used and the analytical procedure for determining carbon, sulphur and alloying elements in cast iron at an American foundry manufacturing Diesel engines and pump castings. The carbon and sulphur are determined by combustion methods and a spectrograph is used for the other elements. A projection-com-parator and a calculating board are used for evaluating the spectro-grams, and these enable the results to be obtained very rapidly.

The Results of Some Supplemental Experiments on the Determination of Silicon by a Quick Method. R. Ishii. (Scientific Papers of the Institute of Physical and Chemical Research, Tokyo, 1940, vol. 37, Mar., pp. 143–146). The author refers to a previous paper describing a rapid method of determining silicon in steel (*see* Journ. I. and S.I., 1940, No. I., p. 312 A). This method was unreliable when the silicon content was below 0·1%. In the present paper some modifications of the method are described which enable it to be applied with reasonable accuracy when less than 0·1% of silicon is present.

Photo-Electric Method of Determining Silicon in Cast Irons and Steels. A. L. Davydov, B. E. Reznik and Z. M. Vaysberg. (Zavods-kaya Laboratoriya, 1939, No. 10–11, pp. 1033–1038). (In Russian). The use of the photo-electric colorimeter enables the determination of silicon with and without a preliminary separation of the iron to be made when the blue silico-molybdate complex obtained by reducing the yellow silico-molybdate complex with stannous chloride is used. If the iron is to be removed first it should be precipitated as phosphate in order to avoid adsorption of the silicon. Both methods give equally accurate results and involve the use of calibration curves, the determination of which is de-scribed. In steels containing 0·1–0·8% of silicon, the accuracy of the determination is within 3–5%, while in cast irons with silicon 0·5–4% the maximum error is 2–5%. The time taken for one determination is 18–20 min.

Colorimetric Determination of Arsenic in Ferrous and Non-ferrous Alloys. C. J. Rodden. (Journal of Research of the National Bureau of Standards, 1940, vol. 24, Jan., pp. 7–11). The author describes a method for the colorimetric determination of arsenic in iron, steel, copper-base alloys, tin- and lead-base bearing metals and pig lead.

Determination of Tungsten. M. L. Holt and A. G. Gray. (In-dustrial and Engineering Chemistry, Analytical Edition, 1940,

vol. 12, Mar., pp. 144–146). The authors have developed a volumetric method for the determination of tungsten, the main feature of which is the reduction of tungstate, in a specially designed apparatus, using liquid lead amalgam as the reducing agent. The resulting trivalent tungsten is reoxidised with ferric iron and the ferrous iron formed is titrated with standard dichromate solution using diphenylamine sulphonic acid as an indicator. Various applications of the new method are described, including the determination of tungsten in ferro-tungsten.

Method of Determining the Gas Content of Molten Steel. A. Samarin and I. Kovalenko. (Stal, 1939, No. 8, pp. 36–39). (In Russian). A somewhat fuller description than that previously given in Zavodskaya Laboratoriya, 1939, No. 7, p. 753 (*see* Journ. I. and S.I., 1940, No. I., p. 280 A), is presented of the construction and use of a gas pipette for taking samples of molten steel and collecting the gases which are evolved during its solidification in a vacuum. The gas sample is finally obtained in a glass bulb which is disconnected from the steel tube pipette used to collect the steel sample, and transferred to a gas analysis apparatus which is also briefly described. The main constituents of the gas samples from basic electric-furnace steel are carbon monoxide, hydrogen and nitrogen, and their determination takes about 15 min. A nomogram for use in calculating gas-sample compositions is given.

Rapid Analysis of Gases in Steel During Melting. P. S. Lebedev. (Zavodskaya Laboratoriya, 1939, No. 10–11, pp. 1131–1138). (In Russian). Two vacuum-pipettes for taking samples of molten steel for gas-analysis purposes have been designed and are described in detail. They are claimed to possess certain advantages over the apparatus designed originally by Piwowarsky. The metallic vacuum-pipette enables accurate determinations of oxygen, hydrogen and nitrogen to be made and also provides a possibility of determining the gases retained by the solidified metal. The ceramic vacuum-pipette enables accurate determinations of oxygen and hydrogen to be made, though the results for nitrogen are inaccurate and the determination of gases left in solidified specimens is impossible. A specially designed mercury-sealed gas analysis apparatus has been designed and is recommended for the work.

Rapid Determination of Oxygen in Steel. L. Singer. (Industrial and Engineering Chemistry, Analytical Edition, 1940, vol. 12, Mar., pp. 127–130). The author describes a method and the necessary apparatus for determining oxygen in steel. In this method reduction takes place in an atmosphere of nitrogen at a temperature of 1200–1250° C., and the oxygen is converted to carbon monoxide, which can then be determined either volumetrically or gravimetrically. A determination can be made in less than 20 min. by this " nitrogen-fusion " method, and it is not necessary for the operators to be skilled in high-vacuum technique.

On a New Indicator Available for the Determination of Nitrogen

Contained in Iron and Steel. I. Wada and R. Ishii. (Scientific Papers of the Institute of Physical and Chemical Research, Tokyo, 1940, vol. 37, Jan., pp. 65–78). The authors describe the method of determining nitrogen in steel which has been adopted by one of the sectional committees of the Japanese Society for the Promotion of Scientific Research. In this method the sample is dissolved in hydrochloric acid and the solution, made alkaline with caustic soda, is distilled. The distillate containing nitrogen in the form of ammonia is received in a sulphuric acid solution. The acid re- maining in the solution is titrated with sodium hydroxide using sodium alizarin sulphonate as an indicator. The authors, however, prefer to use dibromo o-cresol quinoline as an indicator.

A Note on the Determination of Combined Nitrogen in Ordinary and Alloy Steels. H. Kempf and K. Abresch. (Archiv für das Eisenhüttenwesen, 1940, vol. 10, Apr., pp. 419–423). The authors review the more common methods for the determination of nitrogen in steel and show that the solution, bisulphate and extraction methods are sometimes not reliable, whereas the sodium peroxide method always gives satisfactory results. This last method has the disadvantage, however, of not being suitable for serial tests. The authors therefore developed a method which can be used for serial tests and is of sufficient accuracy for a nitrogen content of 0·020%, the error being $\pm 0.0005\%$ to $\pm 0.001\%$. The new method is very similar to the Kjeldahl method used for nitrogen deter- minations in organic substances, the steel sample being decomposed by treatment with concentrated sulphuric acid in the presence of potassium sulphate. After dissolution sodium hydroxide is added and the ammonia distilled off and titrated, using a mixture of methyl red and methylene blue as indicator. The results of a large number of analyses carried out with the new method are listed.

Studies on Quantitative Separation of Metals by Hydrogen Sulphide. Part III. On the Quantitative Separation of Zinc from Iron by Hydrogen Sulphide and the Induced Precipitation of Ferrous Sulphide by Zinc Sulphide. H. Katô. (Science Reports of the Tôhoku Imperial University, 1940, vol. 28, Mar., pp. 480–490).

Spectrographic Analysis of Steel. J. L. Gregg and P. R. Irish. (Iron Age, 1940, vol. 145, May 9, pp. 33–37). The authors describe the instruments and analytical procedure adopted in the spectro- graphic laboratory of the research department of the Bethlehem Steel Co. Several examples of results obtained with this apparatus are given and these show deviations not exceeding 2%, so that for elements present in amounts not exceeding 3%, spectrographic determinations can be made with an accuracy equal to that of standard chemical methods.

BOOK NOTICE

KINZEL, A. B., and R. FRANKS. " *The Alloys of Iron and Chromium. Vol. II.—High-Chromium Alloys.*" First ed. (Alloys of Iron Research, Monograph Series). 8vo. pp. xv + 559. Illustrated. New York and London, 1940 : McGraw-Hill Publishing Co., Ltd. (Price 40s.)

This volume is the eleventh of the series of monographs on iron alloys and the second and final part of the review of information on iron-chromium alloys. Its appearance brings the work begun ten years ago by the Iron Alloys Committee of the Engineering Foundation another step nearer completion, and everyone interested in iron and steel will look forward to the publication of the remaining three volumes dealing with the alloys of iron with vanadium and manganese, and with the iron-nickel alloys not considered in the first volume of the series. The terms of reference of the authors of the various volumes were : To review critically all research on iron and its alloys published since 1890 ; to assemble, correlate and summarise the information thus reviewed ; to supplement it where possible with unpublished data ; and to point out errors, discrepancies and gaps in available knowledge. This general plan has been adhered to throughout the work, and the magnitude of the labour involved is indicated by the fact that the eleven volumes published contain 5635 pages, 1957 illustrations and 1175 tables. In reviewing the published information 20,000 papers have been consulted and 6218 references have been included in the various bibliographies. The preparation of these monographs has been a substantial contribution to the advancement of metallurgical science. A science of this kind develops by the gradual piecing together of information from numerous sources, and the initiation of researches to fill in the blanks. When the literature on a given branch of the science extends to 20,000 papers it becomes impossible for individuals to review the subject for their own edification, and it is only logical that some organised effort should be made to do this once and for all. It is unfortunate that work of this kind cannot be done more frequently, but we have to be thankful that it has at least been done in this particular field. Owing to the resources now available for metallurgical research and development, however, and the universal realisation of the advantages to be derived from such work, information continues to accumulate, and the sponsors of the monograph project, now that their original scheme is nearing completion, will have to consider what they are going to do about keeping this valuable series up to date.

The first volume on the iron-chromium alloys was devoted to those containing less than 10% of chromium, and the present volume is devoted to those containing more. But the first volume also contained a considerable amount of information relating to the alloys generally, *e.g.*, the iron-chromium and the iron-carbon-chromium constitutional diagrams, and although from some points of view this second volume may be considered as an independent work, from other points of view it must be regarded as a continuation of the first volume. As steels

and irons containing more than 10% of chromium are in the main used because of their corrosion- or heat-resisting properties, the present volume is in effect an addition to the literature on alloys of this type. There are already two books in English on alloys of this type, namely, "Stainless Iron and Steel" by Monypenny, and "The Book of Stainless Steels" by Thum, but although all three are devoted to the same general subject, they differ to a pronounced extent in the material selected and the method of presentation. The character of the present volume is implied in the terms of reference to the authors given above, and in accordance with these terms the treatment of each part of the subject is similar to that in previous volumes of the monograph series. After an introductory chapter there are two chapters dealing respectively with the melting and fabrication of high-chromium steels, and at a later stage there is a chapter on the manu-facture and fabrication of austenitic chromium-nickel steels. The remainder of the chapters deal in logical order with the high-chromium steels and cast irons, the austenitic chromium-nickel steels, the chromium-manganese steels and the iron-chromium-aluminium alloys. It is hardly necessary to add that the book will prove invaluable to all who have to do with stainless and heat-resisting steels.

J. M. ROBERTSON.

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MINERAL RESOURCES

Geology and Petrology of the Iron-Ore Deposits of Mandi State, Punjab. S. K. Roy and A. N. Mukherjee. (Quarterly Journal of the Geological, Mining and Metallurgical Society of India, 1939, vol. 11, June, pp. 49–73). The authors describe the geology and petrology of the magnetite deposits of the Mandi State in the Punjab. They also describe the present primitive methods of smelting the ore and state that the introduction of a modern plant to work the Stuerzelberg process is contemplated.

Notes on the Correlation of the Satpukuria Seam in the Raniganj Coalfield. M. M. Mukherji. (Transactions of the Mining, Geological and Metallurgical Institute of India, 1939, vol. 35, Dec., pp. 313–317). The author draws attention to evidence from which he forms opinions differing from those of Gee regarding the stratigraphy of the coal seams of the Satpukuria area. (*See* Geological Survey of India, Memoirs, 1932, vol. 61, p. 256 and Journ. I. and S.I., 1932, No. I., p. 446).

The Iron Mines of Sweden. M. Legraye. (Revue Universelle des Mines, 1940, vol. 83, Apr., pp. 128–133). The author describes the two principal iron-ore fields of Sweden—namely, that of Kiruna and Gellivare in the north and that at Grängesberg in central Sweden. He also gives some data concerning the railways to the nearest ports and the quantities produced and exported in the period 1929–38.

Development of the Low-Grade Manganese Ores of Cuba. F. S. Norcross, jun. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1188 : Mining Technology, 1939, vol. 4, May). In the first part of his paper the author notes the economic importance to the United States of the production of manganese ores in Cuba. In 1931 Cuba supplied less than 1% of the United States imports of manganese ores ; in 1938 the proportion had risen to 27%. He deals next with the geology and methods of mining the ore, pointing out that at the Quinto mine, which produces about 1100 tons per day, the metallic manganese content varies from 13% to 26% ; in fact, at all the mines both ore and gangue show remarkable variations. The author devotes the remainder of the paper to a description of the flotation, milling and roasting processes employed in Cuba.

ORES—MINING AND TREATMENT

Specific Mining Production. K. Rutberg. (Jernkontorets Annaler, 1940, vol. 124, No. 3, pp. 83–102). (In Swedish). The author discusses methods of presenting production statistics for iron-ore mines and the factors affecting such statistics which make it difficult to compare the results achieved at different mines. He presents data relating to Swedish ore production and makes suggestions as to methods of improving the economic efficiency of iron-ore mining.

The Principles of the Beneficiation of Swedish Iron Ores—Notes on Some Actual Problems. S. Mörtsell. (Teknisk Tidskrift, 1940, vol. 70, Mar. 9, Bergsvetenskap, pp. 17–19 ; Apr. 13, Bergsvetenskap, pp. 25–29). (In Swedish). The author discusses the crushing of Swedish iron ores, the classification and proportions of the various particle sizes obtained, and the factors affecting the efficiency of the grinding mills and crushers.

Improvements Necessary in the Design and Operation of Agglomerating Works. A. Seleznev. (Stal, 1939, No. 9, pp. 8–11). (In Russian). On the basis of experience in the design and operation of the agglomerating plant at the Ordzhonikidze works certain unsatisfactory features of the bunker design and in the fuel crushers and sintering plant are considered. In conclusion the author suggests certain improvements in the plant for separating and returning undersized sintered material, and also mentions ventilation requirements in different parts of the plant.

The Magnetising Roasting of Brown Iron Ores. W. Luyken and G. Kremer. (Iron and Steel, 1940, vol. 13, May, pp. 247–251 ; June, pp. 366–370). An abridged English translation is presented of an article which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1938, vol. 20, No. 21, pp. 293–302, in which the author described an investigation of the possibilities of concentrating some of the low-grade red and brown German iron ores by magnetising roasting. (*See* Journ. I. and S.I., 1939, No. I., p. 200 A).

On the Magnetic Roasting of Iron Ores. Y. Gotoh. (Tetsu To Hagane, 1940, vol. 26, Mar. 25, pp. 155–163). (In Japanese). The author presents an account of an investigation of the partial reduction of hematite from the Taikozan, Ohtoen, Higashi Anzan and Nishi Anzan mines, using coke-oven gas. From his laboratory tests he comes to the conclusion that if the ore is reduced with coke-oven gas at 600–700° C. and quenched in air at about 400° C., a magnetically uniform product will be obtained.

A Contribution to the Problem of Ball Wear in Ball-Mill Grinding. S. Mörtsell. (Jernkontorets Annaler, 1940, vol. 124, No. 1, pp. 1–38). (In Swedish). The author commences by pointing out the importance of the wear of balls in ball mills, especially with regard to the grinding of ores. He discusses Davis' theory that the wear of any one of a number of balls in a mill is proportional to its weight, and then describes his own tests, which show that the wear of a ball in a ball mill is directly proportional to the grinding time, and it is therefore constant per unit of time for each ball making up a " charge " and is independent of its size. Some of these tests were carried out with forged and cast steel cubes of different dimensions, which were put in a ball mill for grinding iron ore for various periods of time up to 1700 hr. In other tests balls of three different sizes were used in a small laboratory mill for periods of about 400 hr. For comparison purposes the author uses the symbol μ to represent the coefficient of wear, which he defines as the reduction in diameter in thousandths of a millimetre per hour of continuous grinding. The results of these tests made it obvious that μ is constant for a charge of balls used for continuous grinding, and it is seen from this that the wear of any one ball is not proportional to its weight but to the area of its surface. The introduction of the coefficient μ is very useful in the study of the efficiency of ball and rod mills, and it also provides a means of comparing and selecting balls of different qualities of steel. The author presents calculations based on the above relationship between ball wear and surface area by which the number and size of the balls required can be determined when μ is known. He considers next the causes of non-uniform wear of balls, and, as further evidence in support of his theory, that μ is constant for all the balls of a particular charge without regard to their size, he quotes data respecting the size and wear of balls used in a cylindrical mill at the ore-concentration plant at Rönnskär (in north Sweden). He then discusses some investigations of Gross relating to the influence of the grain size of the ore on the wear of the balls, and, in conclusion, he shows that the results obtained by various investigators, which seem to support Davis' theory, do not in actual fact contradict the author's own theory that the total wear of a charge of balls is equally distributed over the total surface area of the balls.

REFRACTORY MATERIALS

Tailored Firebrick. W. A. Stuart. (Steel, 1940, vol. 106, May 27, pp. 58–61). The author refers to the difficulty of using refractory bricks of the present standard sizes to make arches or complete circles of arbitrary diameter. The 9-in. standard arch-wedge bricks are moulded so that 91 form a circle 4 ft. 6 in. in dia., and larger circles are formed by inserting one or more square bricks either $2\frac{1}{2}$ in. or 3 in. thick. The author proposes that a new standard should be adopted requiring 96 wedge bricks to form the 4 ft. 6 in. circle and that a new standard square brick 9 in. $\times$ $4\frac{1}{2}$ in. $\times$ 2·35 in. ($\frac{3}{4}$ in. $\times$ π) be used with the former to make circles of greater diameter. The adoption of the proposed standards would mean that one 2·35-in. brick would have to be added for each increase of $\frac{3}{4}$ in. in dia. above that of the standard circle. It will be seen that this provides a means of constructing arches over a wide range of diameters in convenient fractions of an inch without having to fill gaps with mortar.

The Action of Alkalies on Refractory Materials. Part IV. The Action of Potassium Chloride Vapour on Refractory Materials at 1000° C. in the Presence of Water Vapour and Air. F. H. Clews, A. Chadeyron and A. T. Green. (Transactions of the British Ceramic Society, 1940, vol. 39, May, pp. 124–135). The present paper is a report on a continuation of the work described in Part II. of this series, which concerns the action of potassium chloride vapour on three refractory materials at 1000° C. (*See* Journ. I. and S.I., 1937, No. II., p. 56 A). In Part IV. data are presented regarding the attack on eight varieties of refractory material by potassium chloride vapour at 1000° C. in the presence of moist and dry air. The authors found that : (1) The presence of water accelerates the rate of combination of potassium chloride in all instances, but notably in the case of silica materials ; (2) under dry conditions the silica products are decidedly less attacked by the alkali than the fireclay, but in the presence of moisture this is not the case, except possibly in the initial stages ; and (3) chemical examination suggests a more uniform distribution of potassium oxide within the brick material with silica products than with fireclay.

The Action of Alkalies on Refractory Materials. Part V. Further Observations on the Action of Potassium Chloride Vapour on Refractory Materials at 1000° C. F. H. Clews, H. M. Richardson and A. T. Green. (Transactions of the British Ceramic Society, 1940, vol. 39, May, pp. 136–146). It has been noted that under service conditions

(*e.g.*, in coke-ovens) silica brickwork seems to resist alkali attack better than fireclay, despite the fact that such action presumably takes place in the presence of some water vapour. As this is not in agreement with the results obtained earlier and reported in Part IV. (*see* preceding abstract), further tests were made which form the subject of the present report. The authors conclusions are : (1) The experimental results reported in Part IV. are confirmed ; (2) the intensity of the previous firing of fireclay materials has an appreciable effect on the reactivity to potassium chloride at 1000° C. ; the harder-fired materials are much less reactive ; (3) the greater the porosity of fireclay materials, the greater is the total increase in weight when exposed to potassium chloride vapour and moist air at 1000° C. The increase in porosity does not appreciably increase the reaction of the chloride ; (4) iron oxide does not appear to cata-lyse the reaction of fired clay with potassium chloride in dry air at 1000° C. ; and (5) hard-fired china-clay and fireclay specimens expand when exposed to potassium chloride and dry air at 1000° C.

Silica in Coke-Oven Practice. E. Alton. (Coke and Smokeless-Fuel Age, 1940, vol. 2, May, pp. 116–118 ; June, pp. 131–134). The author reviews data and the present knowledge concerning the properties of silica with the object of providing coke-oven managers with useful information on the application and behaviour of silica bricks in coke-oven construction. He reproduces Fenner's phase diagram for silica and applies this to the study of the conversion of quartzite in the raw state into its more stable modifications. In the concluding part the author describes methods of determining the extent of the conversion of quartzite and of determining the heat-expansion of silica bricks. He presents a number of tempera-ture-expansion curves for silica bricks burnt to different degrees of conversion.

A Note on Mullite. W. Hugill. (Transactions of the British Ceramic Society, 1940, vol. 39, May, pp. 121–123). The author describes the properties of two distinct crystalline forms of mullite revealed by investigations of the reactions between slags and fire-bricks. Both types are orthorhombic. The normal type has the following refractive indices : $\alpha = 1\cdot642$ and $\gamma = 1\cdot654$, and it usually grows in small crystals. The second form has much lower refractive indices, *viz.*, $\alpha = 1\cdot600$ and $\gamma = 1\cdot610$, and the crystals of this modified mullite grow to a larger size than those of the normal form.

FUEL

Modern Gas Mixing Systems as Applied to Steel Plant Requirements. G. M. Arnold. (Iron and Steel Engineer, 1940, vol. 17, May, pp. 35–43). The author describes some gas-mixing control systems for regulating the heating value and flow of gaseous fuels such as natural gas, refinery gas, blast-furnace gas and coke-oven gas. He presents numerous illustrations, graphs, flow diagrams and calculations relative to the application of such systems at American steelworks.

The Production and Utilisation of Electric Power in the Iron and Steel Industry. C. Berthelot. (Revue de Métallurgie, Mémoires, 1940, vol., 37 Apr., pp. 93–99). The author briefly discusses the power output in the French iron and steel industry, comparing the conditions with those prevailing in Great Britain and Germany. He points out that many French steelworks use blast-furnace and coke-oven gas for the production of electricity, and that sometimes they have a surplus to sell to electric power companies, whilst at other times they require an additional supply from the power companies. The author discusses the economic aspect of this arrangement with particular reference to the conditions in Lorraine.

A Large Coal Preparation Plant. R. D. Hall. (Coal Age : Iron and Coal Trades Review, 1940, vol. 140, May 31, p. 815). The author describes a coal-cleaning plant with a capacity of 4500 tons per day recently installed by the Anthracite Coal Co., at Hughestown, Pennsylvania.

Launder and Table Washing of Fine Coal. J. T. Crawford, C. P. Proctor and J. A. Younkins. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1210, June, 1940). The authors discuss the results obtained at an American coal-washing plant where a system of washing launders placed one below another is used for washing fine coal below $\frac{3}{8}$ in.

Pulverised Fuel. J. R. V. Dolphin. (Colliery Engineering, 1939, vol. 16, Nov., pp. 407–410 ; 1940, vol. 17, Mar., pp. 77–80). In the first part of this series of articles on pulverised fuel the author points out that the maximum flammability of coal dust is obtained when the coal is ground down to a particle size of 10–25 microns. The flammability decreases as the size increases from 25 to 74 microns and the latter size should not be exceeded. He then discusses in turn the questions of safety, velocity of the particles and combustion when using pulverised coal. In the second part the author reviews some of the alternative methods employed in practice to

secure the supply of pulverised coal in a fit state for combustion for a particular purpose.

A Study of New Methods of Heating Coke-Ovens. A. Z. Pash-kevick. (Koks i Khimiya, 1939, No. 9, pp. 22–26). (In Russian). The author reports on coking experiments in laboratory and industrial ovens which showed that the quality of the coke produced was improved (*e.g.*, there was less fissuring) by maintaining a rising temperature in the coke-oven walls instead of a constant temperature. He is of the opinion that this procedure would also shorten the coking time.

Coals Dangerous to Coke-Ovens. R. A. Mott. (Journal of the Institute of Fuel, 1940, vol. 13, June, pp. 189–200). The author reviews the problem of assessing coals dangerous to coke-ovens by reference to data obtained by the Midland Coke Research Committee which were published in a paper entitled '' The Assessment of Coals Liable to Damage Oven Walls '' (*see* Journ. I. and S.I., 1940, No. I., p. 174 A). After considering the advantages and limitations of various German, American and British methods of testing swelling properties, he finds that all tests, whether on a large or small scale, are open to error, and that no universally satisfactory test can be devised unless the cause of the dangerousness of coals to oven walls is known and unless certain precautions are taken in the test. All coking coals must be swelling coals, but swelling power is not of itself the cause of damage to oven walls. In a coke-oven, the shrinkage of the semi-coke outside the plastic layer opposes the swelling pressure of the coal in the plastic layer, and a dangerous pressure is exerted on the oven wall only if the shrinkage does not balance the swelling. The results of investigations emphasise the narrow range within which dangerous coals lie and show that a standardisation based on German coals is not applicable to all types of British coals. In the past undue importance has been attached to swelling pressure and insufficient to the contraction, and, since the contraction under constant load can only be measured satisfactorily in the Koppers swelling test, this test is recommended in preference to the Nedelmann or Baum-Heuser tests. The specification and procedure for the modified Koppers pressure swelling test are given in an appendix.

Coal Carbonisation and Some of Its By-Products. B. W. Haigh. (Transactions of the Mining, Geological and Metallurgical Institute of India, 1940, vol. 35, Feb., pp. 365–391). The author surveys the coal-carbonisation industry, more especially high-temperature carbonisation as practised at by-product coke-ovens and gasworks. He includes some information on the production of power alcohol and high explosives which is of particular interest to India because the Indian benzoles are rich in toluol.

Coke Formation and Coke Combustibility. H. M. Finniston. (Journal of the Royal Technical College, Glasgow, 1940, vol. 4, Jan., pp. 671–695). The author defines the combustibility of coke and

describes a number of laboratory tests which demonstrated the dependence of combustibility on the following factors : (1) Initial temperature of coking ; (2) final temperature of coking ; (3) rate of carbonisation ; (4) time of coking ; and (5) particle size of the coal charge. He found that high values of combustibility are associated with : (a) High initial temperature of coking ; (b) low final temperature of coking ; (c) high rate of carbonisation ; and (d) large particle size of coal charge. From these conclusions the author deduces that the combustibility of coke is a function of the density, the degree of graphitisation and the ash content.

Development in Recovery of Pyridine Bases from By-Product Coke Ovens. M. D. Wald. (Iron and Steel Engineer, 1940, vol. 17, May, pp. 55–58). The author refers to the growing demand for pyridine which has drawn increased attention to the recovery of tar bases present in coke-oven gas. He then briefly describes the semi-direct process of recovering ammonia and points out that there is a loss of pyridine in the gas leaving the saturator in this process. He deals next with the batch process of Dodge and Rhodes in which the pyridine is recovered from the saturator solution, a method which also has disadvantages. Finally, he describes a continuous process of pyridine recovery developed at the Cleveland plant of the Republic Steel Corporation. In this the saturator remains in operation indefinitely ; a small quantity of the saturator solution is continuously withdrawn, stripped of its pyridine content and returned to the saturator. The pyridine content of the bath can be maintained fairly constant at about 1%, and losses are reduced to a minimum. The crude product generally contains about 50–60% of tar bases and about 12–15% of water. The continuous removal of the pyridine materially improves the quality of the ammonium sulphate produced, because pyridine contamination is practically eliminated and the amount of iron salts normally present is reduced.

Desulphurisation of Coke During Quenching. A. Z. Yurovskiy, M. I. Livshits, A. A. Chemeris and N. V. Milfort. (Koks i Khimiya, 1939, No. 10–11, pp. 16–18). (In Russian.) Earlier work on a laboratory scale had shown that sulphidic sulphur could be removed from coke by treating it with an air/water-vapour mixture at 400° C. The present experiments, also on a laboratory scale, have shown that the process could be applied during quenching ; the coke, heated to a temperature of 900° C. or preferably higher, after being first treated with an air/water-vapour mixture (air bubbled through boiling water) until it had cooled to 400° C., was then quenched with water. Desulphurisation was most rapid at elevated temperatures ; the loss by burning during the short time of treatment amounted to only about 2%. An appreciable reduction in the sulphur content was achieved, which, in addition to the maximum temperature, depended on the lump size and the gas-permeability of the coke.

The Behaviour of Coke at High Temperatures. G. M. Isarov. (Koks i Khimiya, 1939, No. 10–11, pp. 13–16). (In Russian). Mechanical properties of coke at, and after, heating to temperatures of 1150–1450° C. were determined. The crushability and resistance to compression and wear were found to be greater at high than at low temperatures for coke which had been subjected to the same heat treatment. An effect of the atmosphere (whether neutral or oxidising) was also noted. Heating to 1450° C. and cooling did not increase the degree of fissuring in the absence of an oxidising atmosphere. The high-temperature behaviour of coke suggested that cracks in it would close up as a result of expansion. A determination of the coefficient of expansion would therefore indicate what size of cracks could be neglected from the point of view of the properties of the coke at high temperatures.

Atmospheric Oxidation of Coal at Moderate Temperatures. L. D. Schmidt, J. L. Elder and J. D. Davis. (Industrial and Engineering Chemistry, Industrial Edition, 1940, vol. 32, Feb., pp. 249–256; Apr., pp. 548–555). In order to determine the susceptibility of coking coals to change during storage, the authors studied, in a specially designed apparatus, the rates of oxidation at low temperatures—i.e., below 100° C.—of samples from eight different coal-beds. They also investigated the effect of pre-oxidation on the carbonising properties of these coals. They found that progressive oxidation results in decreased pore size of the coke, followed by poor fusion and, finally, complete loss of coking properties. The specific gravity of coke increases with oxidation of the coal. At the same time, however, there is, in general, a decrease in the strength of the coke and in the yield of by-products.

How Problem of Economic Recovery of By-Products from Blast-Furnace Gas was Solved. W. J. Dunnachie. (Journal of the West of Scotland Iron and Steel Institute, 1940, vol. 47, Feb., pp. 67–68). The author relates some of the history of the research on the question whether blast-furnace gas contained sufficient tar and ammonia to justify the installation of a recovery plant. He refers in particular to his own work in 1880, the results of which led to the erection of by-product recovery plants which were successfully operated in conjunction with many blast-furnaces in Scotland.

Kinetics of Hydrogen Consumption, Oxygen Removal and Lique-faction in Coal Hydrogenation : Effect of Rank. C. H. Fisher, G. C. Sprunk, A. Eisner, L. Clarke, M. L. Fein and H. H. Storch. (United States Bureau of Mines: Fuel in Science and Practice, 1940, vol. 19, Jan.–Feb., pp. 13–16; Mar., pp. 51–55; Apr., pp. 67–68). The investigation here described of the effect of the rank of a coal (as determined by United States Bureau of Mines standards) on the consumption of hydrogen in the hydrogenation process showed that variations in rank had little effect on the rate of consumption, and that the fraction of oxygen in the

anthraxylons which is rapidly eliminated as carbon dioxide and water in the early stages of the reaction increases with decreasing rank.

Hydrogenation of Cannel Coals and Their Petrographic Constituents. C. H. Fisher, G. C. Sprunk, A. Eisner, L. Clarke, M. L. Fein and H. H. Storch. (United States Bureau of Mines : Fuel in Science and Practice, 1940, vol. 19, May, pp. 84–89 ; June, pp. 110–118). Continuing their investigation of the suitability of different types of American coals for hydrogenation, the authors now report on the results obtained when hydrogenating cannel coals of different petrographic composition. Cannel coals were found to be similar to splint or dull coals, in that they are heterogeneous and give yields and types of oil that depend largely on the nature of the cannel. High yields of inert residue are obtained when, as is frequently the case, the opaque attritus content of the cannel coal is high.

Tests on the Liquefaction of Canadian Coals by Hydrogenation. T. E. Warren and K. W. Bowles. (Canada Bureau of Mines, 1938, Publication No. 798). The authors describe the apparatus developed by the Bureau of Mines of Canada for continuous hydrogenation on a small scale and the hydrogenation tests made with it on numerous samples of Canadian bituminous coals.

The Production of Oil from Coal by the Fischer-Tropsch Process. K. C. Appleyard. (Year Book of the Coke Oven Managers' Association, 1940, pp. 258–281). The author describes the technical aspects of the Fischer-Tropsch process of producing oil from coal and concludes with a discussion of the types and properties of the oils which can be produced.

PRODUCTION OF IRON

Details of Design—No. 5 Blast-Furnace, Inland Steel Co. H. W. Johnson. (Iron and Steel Engineer, 1940, vol. 17, Apr., pp. 22–35). In this detailed description of the design of the No. 5 blast-furnace of the Inland Steel Co., Indiana Harbour, and its auxiliary equipment, the author pays particular attention to the manner in which the coke and ore are stored and transferred to the skips. He discusses also the distribution and temperature of the gases in the stock column and the relation between the various internal dimensions of the furnace. The method of controlling the blast temperature is also of interest. At all the blast-furnaces at these works cold air from the engine-room is mixed with hot air from the stoves, and it has been found that the position of the mixing point had an important effect on the uniformity of the blast temperature. The best results were achieved by introducing the cold air at the bottom of the hot-blast valve drum on each individual stove.

Desulphurisation of Pig Iron with Soda. C. G. Carlsson. (Jern-kontorets Annaler, 1940, vol. 124, No. 3, pp. 103–115). (In Swedish). The author reviews the results obtained by Körber and Oelsen in their laboratory experiments on the desulphurisation of pig iron with sodium carbonate and sodium silicate (*see* Journ. I. and S.I., 1938, No. II., p. 343 A) and discusses the experience gained in full-scale operations at works in Germany, France, Belgium, Luxemburg and England.

The Reduction Equilibria of Oxides and Oxide Mixtures as the Basis of Important Problems in the Production of Iron. F. Körber and W. Oelsen. (Zeitschrift für Elektrochemie, 1940, vol. 46, Mar., pp. 188–194). The authors report on investigations based on the work of R. Schenck and his collaborators (*see* Journ. I. and S.I., 1938, No. I., p. 249 A). In the first and second chapters of the paper the authors discuss the reduction equilibria of ferrous-oxide/manganese-oxide solid solutions and of iron-manganese silicates, and they consider the influence of these equilibria on the composition of inclusions in steels deoxidised with manganese and/or silicon. In the third chapter conclusions of theoretical and practical importance are drawn from Schenck's study of the reduction of iron phosphates, and it is pointed out that inclusions in commercial iron cannot contain any phosphate, unless the phosphorus content is extraordinarily high —*i.e.*, above 0.07%. The authors consider also the influence of the presence of silica on the reduction of iron phosphates.

The Possibilities of the German Iron Industry. Its Efforts to

Become Self-Sufficient. L. Descroix and A. de Riva-Berni. (Revue de Métallurgie, Mémoires, 1940, vol. 37, Feb., pp. 48–60 ; Mar., pp. 71–85). In this review of the position regarding the supplies of iron ore available in Germany the authors deal in turn with the ores which used to be worked in the Ruhr district, the beneficiation of the Siegerland ores, the recovery of iron from pyrites residues near Meggen, the operations at the new mines at Kahlenberg and Schönberg in Baden, the use of raw materials other than iron ores and the recovery of by-products.

The Possibilities of the German Iron Industry. (Addendum.)—Incorporation of the Renn Direct Process into the Economic Plan. L. Descroix and A. de Riva-Berni. (Revue de Métallurgie, Mémoires, 1940, vol. 37, Apr., pp. 123–126). This is an abridged French translation of the paper published by H. Bansen in Stahl und Eisen, 1939, vol. 59, July 6, pp. 785–790. (*See* Journ. I. and S.I., 1939, No. 2, p. 200 A).

The Heavy Industries of Italy. (Iron and Coal Trades Review, 1940, vol. 140, June 14, pp. 877, 885). A review is presented of the economic position of Italy with regard to the home production and imports of iron ore, pig iron, steel, coal and coke. It is shown that the efforts to increase the output of iron ore are expected to bring the annual production up to about 1,400,000 tons, which is about half of Italy's requirements. The production of pig iron has risen from 460,000 tons in 1932 to 928,000 tons in 1938, and it is proposed to increase this up to 1,500,000 tons per annum, mainly by an increase in the use of pyrites cinder and the installation of electric furnaces. The increased use of electric furnaces for steelmaking is also noteworthy, their output having risen from 211,000 tons in 1929 to nearly 700,000 tons in 1938, in which year a total of 2,322,000 tons of steel was produced. Italy is now importing about 1,000,000 tons of coal per month from Germany, but the import of coke has been reduced to negligible quantities by the building of large batteries of coke-ovens in the northern industrial areas.

Heavy Industries of Manchoukuo. (Iron and Coal Trades Review, 1940, vol. 140, Apr. 26, pp. 635–636 ; May 3, pp. 690, 694). This article is an abridged version of Report No. 3 of an East Asia Economic Intelligence Series issued by the Office of the Japan Economic Federation, Tokyo. Particulars are given of the estimated coal and iron-ore reserves of Manchuria and of the coalfields, collieries and iron-ore mines worked, as well as of the Showa Steel Works and the Penhsihu Coal and Iron Co.

FOUNDRY PRACTICE

Gray Iron Foundry Practice Moves Forward. C. H. Lorig and V. H. Schnee. (Foundry, 1940, vol. 68, May, pp. 90–91, 161, 164–166). The authors review the literature from January, 1938, to December, 1939, on foundry practice in the production of grey iron castings. A bibliography with 89 references is appended.

Gas in Liquid Cast Iron. W. Y. Buchanan. (Institute of British Foundrymen, June, 1940, Paper No. 711 : Foundry Trade Journal, 1940, vol. 62, June 13, pp. 439–442, 448). The author describes some investigations the principal object of which was to study the relation of the moisture content of the blast supplied to a cupola to the amount and composition of the gases evolved from the molten metal and to the porosity of the solid metal. He describes the apparatus designed by Ambler for making the gas analyses and reviews the literature on earlier investigations of the effect of moisture in blast-furnace blast. The author's experiments in adding water to the blast of a 32-in. cupola had the following effects on the composition of the gas evolved from the molten metal : (*a*) A decrease in the carbon monoxide from 24% to 8% ; (*b*) an increase in the hydrogen from 14% to 24% ; (*c*) a decrease in the methane from 2·92% to nil ; and (*d*) an increase in the nitrogen from 58% to 68%. Further experiments with an 18-in. cupola showed that the addition of water to the blast increased the rate of gas evolution from the metal normally melted from 15–17 ml. per min. to 24–28 ml. per min. From the author's report on the investigation of the effect of adding 4% of steel turnings to the ladle on the rate of evolution of gas from the metal, it is seen that when the initial gas content was low the rate was reduced by 30%, and when the initial content was high the reduction was 54%. As to the gas composition, the principal changes were : (*a*) Very slight increases in the oxygen and carbon monoxide ; (*b*) the hydrogen decreased from 7% to nil ; (*c*) the methane increased from nil to 20% ; and (*d*) the nitrogen decreased from 74% to 58%. Some tables showing the effect of ladle additions of steel turnings on the analysis and mechanical properties of the cast metal are also given.

Making Better Machine-Tool Castings. F. J. Dost. (Mechanical Engineering, 1940, vol. 62, May, pp. 365–369). The author describes the foundry technique adopted in order to produce a hard but machinable cast iron for machine-tool castings. He found that by charging a high proportion of steel (over 70%) in the cupola and controlling the total carbon at 2·70–2·85%, an excellent iron for

the ways of a lathe bed was obtained. Scoring of the wearing surfaces did sometimes occur, however, and the author gives an account of a study lasting two years which was made to determine the cause of this. By making many comparisons between micrographs showing the structure of iron which had scored and that which had given many years' good service, it was eventually established that a peculiar structure was visible only in the specimens from the scored metal. This structure has been called " primary ferrite," " eutectic," " pseudo-eutectic " and " supercooled." Its nature was that of a comparatively soft mass of ferrite and graphite. In conclusion he explains why the formation of this structure was prevented by making ladle additions of amorphous graphite together with ferro-chromium and ferrosilicon.

Deformation and Flowability Tests of Moulding Sands. R. Chadwick. (Institute of British Foundrymen : Foundry Trade Journal, 1940, vol. 62, June 6, p. 416). After discussing some definitions of the deformation and flowability of moulding sands, the author presents the results of some investigations of the deformation and flowability of (a) samples of silica sand with increasing proportions of clay ; (b) sand mixed with coal dust ; and (c) green sand with increasing proportions of moisture. He comes to the following conclusions : (1) There is a definite relation between the flowability and the deformation ; (2) these properties are most easily controlled by varying the clay content or the moisture content, but the means adopted must depend on other properties required of the sand ; (3) the flowability test is most useful in the control of hardness ; and (4) in order to obtain the fullest information, the deformation should be recorded at intervals as the load on the test-piece is increased.

Development of Some Gating and Feeding Methods for High-Duty Alloys. A. E. Cartwright and C. C. Brisbois. (Institute of British Foundrymen, June, 1940, Paper No. 708 : Foundry Trade Journal, 1940, vol. 62, June 13, pp. 443–448). The authors describe the special methods of feeding and gating adopted at a Canadian foundry producing a large variety of castings of low-carbon high-strength grey iron and alloy cast irons such as Ni-Resist and Ni-Hard. They stress the advantages obtained by direct-riser pouring and describe the general design of direct-pouring feeder heads.

Producing Sound Castings in Iron. P. D. Pincott. (Institute of British Foundrymen : Foundry Trade Journal, 1940, vol. 62, June 6, pp. 417–419 ; June 13, pp. 452–453). The author reviews and examines some of the difficulties which are connected with unsoundness in iron castings, describing as examples those overcome at the works with which he is connected. These examples include the design of feeder heads for making up the shrinkage of molten low-carbon iron in the case of compressor cylinder castings, and the feeding arrangements for casting heavy flywheels for

" Texrope " drives which require the subsequent machining of V grooves in the periphery.

Production of Pressure-Resisting and High-Duty Iron Castings. J. L. Francis. (Institute of British Foundrymen, June, 1940, Paper No. 707). The author describes in detail the procedure followed in the manufacture of straight and alloyed grey-iron castings weighing from a few ounces to 2 tons. The procedure relates to the production of small numbers of high-quality castings such as rotors, couplings, pistons, compressor cylinder bodies, valve bodies, motor casings and engine bedplates.

Changes Methods to Reduce Cylinder Casting Loss. J. E. Olson. (Foundry, 1940, vol. 68, May, pp. 88–89, 171–174). The author describes the former and the present moulding and pouring technique for the production of jacketed cylinder castings for internal-combustion engines. He explains why casting with the mould in a horizontal position produced better castings and less scrap than when the mould was kept vertical.

Electric Motor Castings in Green Sand. J. Hird. (Institute of British Foundrymen : Foundry Trade Journal, 1940, vol. 62, May 23, pp. 379–381 ; May 30, pp. 401–402). The author describes the moulding technique adopted for making a green-sand mould for an electric motor casing, 4 ft. 6 in. in dia. weighing 22 cwt., and the end covers for the same motor.

Moulding a 100-Ton Three-Ram Press Casting. R. F. Coates and J. King. (Foundry Trade Journal, 1940, vol. 62, June 6, p. 415). The authors describe how a pattern was improvised and a mould prepared for making a hydraulic press casting weighing 11½ tons, the original pattern for which had been destroyed.

Some Observations on Contraction in Grey Cast Iron. E. Longden. (Institute of British Foundrymen, June, 1940, Paper No. 712 : Foundry Trade Journal, 1940, vol. 62, June 13, pp. 432–434, 438). The author describes a number of tests made to measure the changes in the contraction rates of large iron castings between the solidification and atmospheric temperature. The castings tested included a lathe bed, a boring bar 18 in. in dia., 45 ft. long, a second one 22 in. in dia., 47 ft. long, and the bed of a grinding machine 41 ft. 6 in. long. A number of cooling curves in which the linear contraction is plotted against time are presented. From the data obtained the author draws two main conclusions : (1) Where members of different section are linked together as a single-piece casting in such proximity as to be subject to the same influences, thick bars or sections contract more than thinner bars or sections ; and (2) if the same contrasting sections are cast as simple uniform and separate items, the contraction is in accordance with the standard allowance and knowledge—*i.e.*, a thin section of grey iron contracts more than a thicker section for the same analysis. In explanation of the contrary nature of these conclusions, the author observes that a study of the very clear arrest and expansion

periods noted on the cooling curves indicates that a thick section of a casting may be undergoing an expansion at a time when a thinner section has passed its expansion phase and is in a contracting state ; under such conditions the thin sections will suffer extensional stress.

Formation of Inclusions in Steel Castings. W. Crafts, J. J. Egan and W. D. Forgeng. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1184 : Metals Technology, 1940, vol. 7, Apr.). The authors report on an investigation of the relationship between the types of inclusions found in steel castings, their ductility and empirical ternary solidification diagrams for the metal, its oxides and sulphides. Their experiments were carried out on a series of melts of $0 \cdot 30$–$0 \cdot 35\%$ carbon steel deoxidised with additions of aluminium graduated from $0 \cdot 025\%$ to $0 \cdot 10\%$, and in one case with calcium and aluminium so as to produce five types of inclusions—namely, silicate, eutectic, clusters, alumina and peritectic. The authors emphasise that their solidification diagrams are not only not quantitative, but are conjectural in many respects ; they believe, however, that their diagrams do broadly represent the mechanism by which the inclusions were formed. A study of these diagrams provides an explanation of the high ductility usually obtained in steel with silicate inclusions when treated with large $(0 \cdot 10\%)$ additions of calcium, for it is seen that calcium does not appear to form inclusions of the oxy-sulphide compound type. The proneness of steels with the silicate and eutectic inclusions to hot-tearing is explained by the absence of the oxy-sulphide compound as a buffer between atmospheric oxidation and the intergranular eutectic which seriously lowers the resistance of steel castings to hot-tearing.

PRODUCTION OF STEEL

Open-Hearth Furnace Plant of the Blaenavon Co., Ltd. (Iron and Steel, 1940, vol. 13, June, pp. 360–362). A brief illustrated description is given of the new steel furnaces of the Blaenavon Co., Ltd., in South Wales, and some of the auxiliary equipment. There are two 40-ton acid open-hearth furnaces fired by a battery of three Stein-Chapman gas producers.

Kembla's New Open Hearth Furnace. F. Gross. (Broken Hill Proprietary Review, 1940, vol. 17, Apr., pp. 14–16). An illustrated description is given of the 250-ton open-hearth furnace which was put in commission at the Kembla Works of Australian Iron and Steel, Ltd., in January, 1940. The hearth is laid with 55% and 45% magnesite bricks and the roof is constructed of silica bricks. In order to prevent damage to the roof by overheating, there is a carborundum " target block " in the centre of the roof and automatic roof-temperature control is installed ; this cuts off the fuel when the roof temperature reaches 2950° F. and turns it on again after a drop of 20° F. The new furnace, with the exception of the roof, is completely insulated to the ground level with $1\frac{1}{2}$ in. of special insulating material. The furnace is giving satisfactory service and has produced up to 2963 tons in a week.

Notes on the Expansion of the Fagersta Steel Works Combine Since Its Formation. (Swedish Export, 1940, vol. 24, May, pp. 53–57). An illustrated account is given of the history of the development and the present plant at the works of Fagersta Brukskoncernen, which is a combine embracing the steelworks of Fagersta, Kloster, Forsbacka, Horndal and Dannemora. The total production of the combine has increased from 80,000 tons in 1927 to about 170,000 tons. The total number of staff and workmen employed is now about 6000. At the Fagersta works there is the world's largest store of charcoal, holding about one million sacks of this fuel. In common with other Swedish works of this character, the combine has a home farm which supplies dairy and farm produce to the employees.

The Beginning of the Thomas Process of Manufacturing Steel in Japan. K. Imaizumi. (Tetsu To Hagane, 1940, vol. 26, Mar. 25, pp. 183–191). (In Japanese).

" Tailor-Made " Steels. T. Grey-Davies. (Sheet Metal Industries, 1940, vol. 14, Feb., pp. 127–129). Continuation of a series of articles (*see* p. 185 A). In Part XVI. of this series the author describes the basic and acid open-hearth processes of steelmaking and some of the characteristics of the steel made by these two processes.

The Heat Control in Open-Heath Furnace Operation. N. Toper-verkh. (Stal, 1939, No. 9, pp. 56–58). (In Russian). While completely automatic control of the thermal state of an open-hearth furnace is desirable, partial automatic control and certain temperature measurements can prove very effective without necessitating large capital outlay. The author considers under this heading : (1) Roof temperature measurements ; (2) the measurement and control of the pressure in the space above the bath ; (3) signalling to indicate the need for valve reversal (the actual reversing being done manually) and the measurement of metal temperatures with an optical pyrometer. On the basis of practical experience, pressure control in the space above the bath by automatic hydraulic regulation of the damper in the smoke stack is regarded as being of particular value.

Some Aspects of Electric Furnaces for the Melting of Metals. G. R. Bashforth. (Iron and Steel, 1940, vol. 13, Feb., pp. 148–150 ; Mar., pp. 191–194 ; May, pp. 255–259). The author's paper before the Staffordshire Iron and Steel Institute, in which he discusses the developments in electric-furnace design, is reproduced. (*See* Journ. I. and S.I., 1940, No. I., p. 82 A).

Transporting Hot Ingots. L. Mandel. (Broken Hill Proprietary Review, 1940, vol. 17, Apr., pp. 10–11). The author describes two new ingot transfer cars and the remote-control system at the Kembla Works of Australian Iron and Steel, Ltd. This installation enables ingots to be taken from any position in the casting bay to a position opposite any particular soaking-pit. The two cars when fully loaded with four ingots weigh 65 tons. They run on standard-gauge track and are hauled by an endless wire rope and drum driven by a 130-h.p. motor. The system of electrical control and braking is also described.

ROLLING-MILL PRACTICE

The Second Blooming Mill of the Magnitogorsk Works. A. Smolyakov. (Stal, 1939, No. 9, pp. 44–47). (In Russian). Brief details with illustrations are given of the mill stand and accessory equipment at the new blooming mill at the Magnitogorsk Works.

Tata's 24-in. and 18-in. Morgan Continuous Sheet Bar and Billet Mill. S. D. Gupta. (Tisco Review, 1940, vol. 8, May, pp. 370–372, 376). The author describes the development of the rolling mills of the Tata Iron and Steel Co., and the installation in 1924 of a Morgan continuous mill for rolling billets and sheet bars. The mill now comprises six stands of 24-in. rolls and six stands of 18-in. rolls with two vertical edging stands.

Continuous Production Methods for Stainless Steel. T. J. Ess. (Iron and Steel Engineer, 1940, vol. 17, May, pp. R-1–R-15). The author presents a detailed and fully illustrated description of the electric furnaces and rolling mills for the production of stainless steel strip at the works of the Republic Steel Corporation.

Power Requirements of Cold Strip Mills. A. F. Kenyon. (Iron and Steel Engineer, 1940, vol. 17, May, pp. 19–31). The author discusses methods of calculating the electric power requirements for the cold-rolling of steel strip. He first describes the steps in the preparation of energy-consumption curves from test data and the application of the curves to calculate the individual motor loads for a specific rolling schedule. He then analyses and compares typical energy-consumption curves for rolling various strip products, and in conclusion presents data relating to the mill output and consumption of electrical energy at several American rolling mills producing various classes of strip.

Ventilation of Electrical Machinery at a Steel Rolling Mill. (Engineer, 1940, vol. 169, Apr. 19, p. 380). An illustrated description is given of the forced-ventilation equipment for the electrical machinery driving the new steel strip mill at the works of John Summers and Sons, Ltd.

The Transition from 25 to 60 Cycle Power in the Steel Industry. W. B. Skinkle. (Iron and Steel Engineer, 1940, vol. 17, Mar., pp. 45–48). The author discusses the reasons which led to the change-over from 25 to 60 cycles per sec. A.C. at the works of the United States Steel Corporation, the Carnegie-Illinois Steel Corporation and the National Tube Co., all of which are in the Pittsburgh district.

PYROMETRY

Measuring Open-Hearth Bath Temperatures. L. O. Sordahl and R. B. Sosman. (American Institute of Physics : Steel, 1940, vol. 106, May 20, pp. 44–47). The authors describe seven different methods of determining the temperature of steel in an open-hearth furnace which were investigated and compared over a ten-day period. These methods were : (1) Determination by means of a platinum-rhodium/platinum thermocouple in a porcelain tube within a graphite tube. (2) The test-spoon method in which readings were taken with a disappearing-filament pyrometer of the molten metal in a sampling spoon. (3) The Larsen and Shenk bath-equalisation method in which one photo-electric pyrometer was sighted on the inner surface of the roof and a second one was sighted on the surface of the slag. The two circuits were connected in opposition. The fuel and air supplies were shut off when the temperature was to be taken and in about twenty seconds the radiation from the slag and the roof reached a state of equilibrium. When this occurred, a relay connected to the instruments auto-matically turned on the fuel and air. The lowest temperature recorded by the pyrometer sighted on the roof during this procedure was taken as the bath temperature. (4) The " rod-boil " method, in which a cold steel rod was pushed into the bath and an optical pyrometer was sighted on the surface of the metal as it boiled up through the slag near the rod. (5) An optical pyrometer was used when the gas valves were being reversed to take readings on the interior of a gas bubble just as it burst. (6) The temperature of the bath was estimated from a series of readings with an optical pyro-meter sighted on a bright area of the slag. (7) Readings were made with a Collins-Oseland tube with an optical pyrometer at one end and an orifice at the other end which was immersed in the molten metal.

The authors discuss the practicability of these methods and the accuracy of the readings obtained. Eventually they developed an improvement of method (7) which consisted in substituting a photo-electric cell for the pyrometer and connecting this cell to an amplifier and recording instrument. As the current produced by the cell varied approximately as the twelfth power of the absolute temperature of the radiating surface, the lower and unimportant temperatures were recorded on a narrow strip of the chart and the important refining temperatures were recorded on a much larger scale. The apparatus is claimed to be sufficiently robust for steel-plant conditions and to require little maintenance.

HEAT TREATMENT

The Carburising of Stainless Steel. E. Zhukovin. (Stal, 1939, No. 9, pp. 54–55). (In Russian). Experiments with a stainless steel (13–15% of chromium, 0·6% of nickel, and up to 0·15% of carbon) carburised at 900° C. in a carburising mixture of the usual composition, showed that after quenching from an optimum temperature of 920–940° C. an average hardness of Rockwell C 55 was obtainable. The carburising of low-carbon stainless steel renders it suitable for parts of measuring instruments and for dies for moulding synthetic resin without the need for chromium-plating.

Carburisation with Special Reference to the Use of Solid Carburising Agents. F. W. Haywood. (Metallurgia, 1940, vol. 22, May, pp. 22–24). The author explains the mechanism of the migration of carbon from solid carburising agents to the steel which is to be case-hardened. He also explains the function of energisers such as the carbonates of sodium, potassium, calcium and barium. He then describes the equipment used for box-carburising and the practical precautions to be taken to ensure good results. He concludes with a brief discussion of the processes of liquid and gas carburising.

Flame-Hardening from the Standpoint of the Commercial Heat-Treater. W. G. Hamilton. (Welding Journal, 1940, vol. 19, Apr., pp. 253–255). After a brief description of the flame-hardening process, the author describes and illustrates two flame-hardening machines at the works with which he is connected. One is for gear teeth, and the other is a circular machine within which the work can be spun. He discusses some of the advantages of using this process.

Nitriding Steels. H. H. Jackson. (Aircraft Production, 1940, vol. 2, July, pp. 220–222). The author discusses some of the variables, particularly those associated with non-austenitic material, which affect the quality of nitrided steel. In low-capacity furnaces poor circulation may result from the small flow of gas required to give a workable dissociation of the ammonia. It is advisable that a definite dissociation ratio be applied to each individual furnace and that the charges for any one furnace should be of approximately equal surface area. Aspects of material quality which affect the nitriding process are usually confined to decarburisation, non-metallic inclusions, excessive grain size, grain flow, composition and incorrect microstructure. For selective nitriding the areas not to be hardened are plated with tin, and to prevent the running of the tin on to a surface prepared for nitriding, the author recommends tinning to a thickness of about 0·001 in. in an acid bath, heating to

$500°$ C. for 2 hr., and then grinding the surfaces to be nitrided. He stresses the fact that to obtain a perfectly uniform nitride case the surface of the steel must be both chemically and structurally uniform, and suggests that regular hardness tests be made on components prior to treatment; any parts which are found to be harder than normal should be examined microscopically and reheated if necessary.

Heat Treatment of Metals. R. C. Stewart. (Canadian Metals and Metallurgical Industries, 1940, vol. 3, Apr., pp. 92–96). After explaining the changes in structure which steel undergoes when subjected to heat treatment, the author describes some of the furnaces and quenching media used and their particular applications. He also gives data relating to some special examples of heat treatment with particular reference to expansion, contraction and warping. In conclusion he describes the hardening of die steels by oil-quenching.

The Heat Treatment of Tool Steels. (Machinery, 1940, vol. 56, June 20, pp. 355–358). The heat-treatment schedules for carbon-steel tools having been presented in a previous article (*see* p. 60 A), the present article deals with the heat treatment of high-speed steel. All high-speed steel should be annealed after forging and before machining, or before rehardening. As the hardening is done by quenching from a high temperature (2200–$2500°$ F.), a preheating treatment at about 1550–$1600°$ F. is usually given, the time for which the steel is held varying from 5 min. for $\frac{1}{4}$-in. thick steel to 2 hr. for 6-in. steel. Several tables are presented in which the cutting efficiency and hardness of different tool steels are related to the hardening and tempering temperatures. In conclusion the problem of dimensional changes during heat treatment is dealt with; such changes range from 0.03% to 0.2%; both the hardening temperature and the holding time should be as low as is practicable to keep at a minimum the dimensional changes in tools that are not to be ground after hardening.

A General Outline on the Heat Treatment of High-Speed Steel. H. W. Pinder. (Metallurgia, 1940, vol. 22, May, pp. 27–29). The author commences his discussion of the heat treatment of high-speed steel by describing the annealing of the ingot before forging and cogging, and the second annealing after the final stage of hot-working before machining. He explains the reasons for the different hardening and tempering temperatures of (*a*) 14% tungsten steel; (*b*) 18/4/1 tungsten-chromium-vanadium steel; (*c*) steel containing 20% of tungsten and 5% of cobalt; (*d*) steel containing 20% of tungsten and 18% of cobalt; and (*e*) steel containing 2.5% of tungsten, 4% of chromium, 1% of vanadium and 8.5% of molybdenum. Turning to the practical side of the heat treatment, the author discusses the conditions which exist in the chamber of the hardening furnace and the effect of variations in the period during which the tool is held at high temperature. He concludes with some observations on tempering, and recommends that (*a*) 18%

tungsten high-speed steels should be given one complete cycle, *i.e.*, one heating and cooling ; (*b*) 5% and 10% cobalt steels should be tempered twice ; and (*c*) 18% cobalt steels may be tempered three times.

Heat-Treatment Plant at Brown, Bayley's. (Iron and Coal Trades Review, 1940, vol. 140, May 31, pp. 811–814 ; June 7, pp. 849–851). A fully illustrated description is given of the heat-treatment plant recently installed at Brown, Bayley's Steel Works, Ltd., Sheffield. The plant includes gas-fired and electric furnaces for the heat treatment of steel tyres and bars.

The Heat Treatment of Wire and Wire Products. (Wire Industry, 1940, vol. 7, May, p. 211). Continuation of a series of articles (*see* Journ. I. and S.I., 1940, No. I., p. 289 A). Some particulars are given relative to the use of a salt mixture known as " Carboneutral " for hardening tools. The salt liquor can be used at temperatures between 1036° and 1370° C., which is sufficiently high for annealing high-speed steels.

Controlled Atmospheres—Their Influence in the Heat Treatment of Steel. A. Fisher. (Machinery, 1940, vol. 56, June 13, pp. 321– 325). The author discusses how the heat treatment of steel is affected by furnace atmospheres of different compositions, including free air, flame-curtain atmospheres, coal-fired open-furnace atmospheres, cracked ammonia, town gas, natural gas and partially burnt hydrocarbon gases. He also gives some information on the gases generated by cast-iron borings when used for close-annealing, and by carburising compounds.

New Burner System Features Wider Temperature Range and Closer Control. H. M. Heyn. (Industrial Heating, 1940, vol. 7, Apr., pp. 312–314). The author describes a system of twin burners for use with convection heat-treatment furnaces working at temperatures up to about 1350° F. The system is known as " Conjecto-Firing," and its object is to facilitate the supply of a large volume of hot gases when the burners are turned down for low-temperature heat treatment. The control devices are so arranged that at a specified low temperature an additional volume of air is introduced through the lower nozzle into the combustion chamber of the furnace.

Steel Plant Furnaces—Section 4. Furnaces for Sheets and Strips. Parts II. and III. M. H. Mawhinney. (Industrial Heating, 1940, vol. 7, Feb., pp. 136–142 ; Apr., pp. 299–302). Continuation of a series of articles. In Parts II. and III. the author describes some batch and continuous furnaces, the latter with chain or roller conveyors, for the heat treatment of steel sheets and strip.

Cooling System for Quenching Oil. (Iron Age, 1940, vol. 145, May 27, p. 31). An efficient and inexpensive system for the cooling of quenching oil is described. It comprises pumping the hot used oil to a tank in the top of the plant building and allowing it to overflow down a wide sheet-metal chute which presents a large cooling surface to the atmosphere. The oil is collected in a tank at the bottom and pumped back to the quenching tank.

WELDING AND CUTTING

The Fundamental Nature of Welding. D. E. Babcock. (Welding Journal, 1940, vol. 19, Apr., pp. 141-S–145-S). In the first part of his paper the author considers the effect produced by the current in spot and resistance welding on the grain size and structure of the metal in and adjacent to the weld. In the second part he relates the physical properties of the welded joint to the structure of the metal.

Proposals for a Standard Measure for the Classification of the Coating Thickness of Electrodes. G. Haim and H. P. Zade. (Welding Industry, 1940, vol. 8, June, pp. 152–156). As they found it useful to classify welding electrodes by their coating thickness, the authors have developed a classification system on this basis, which is explained in the present paper. The symbol $R.T.$ (the relative thickness in tenths of a millimetre) is used to express the difference between the outside and core diameters of an 8 S.W.G. electrode, and the relative thicknesses for all other gauges are developed by maintaining the same welding properties of the 8 S.W.G. electrode, which is done by varying the diameter of the coating until such welding properties are obtained ; the coating diameters found in this way are given the same $R.T.$ number. The authors present two graphs ; one consists of a series of curves, one for each $R.T.$ number, which enables the coating thickness for any gauge of electrode to be easily read off, whilst the second series gives the same dimension relative to the electrode volume.

Recovery of Silicon in Oxyacetylene Welding Cast Iron. P. R. Hall and R. M. Allen. (Welding Journal, 1940, vol. 19, Apr., pp. 130-S–132-S). The authors report on an investigation undertaken to determine how much of the silicon in a cast-iron welding rod remains in the weld metal when oxy-acetylene welding cast iron. Rods were used with silicon contents in the range 2·47–4·46%. The general conclusion was that there was no absolute correlation between the silicon content of the rods and the properties of the welds. The indications were that a higher proportion of silicon was lost from the high-silicon rods. The physical properties of the welds were seriously affected when there was less than 2·50% of silicon in the rod, and the most satisfactory welds were made with rods containing 2·75–3·50%.

Welding of Cast Iron. L. Tibbenham. (Institute of British Foundrymen : Foundry Trade Journal, 1940, vol. 62, May 23, pp. 377–378). The author describes the theory and practice of the welding of iron castings, with particular reference to the need for

preheating and slow cooling. In conclusion he discusses the advantages of repairing broken castings by bronze welding.

A New Method of Welding Galvanized Sheets. A. R. Eckberg. (Welding Journal, 1940, vol. 19, Apr., pp. 293–294). This is a reproduction of an article which appeared previously in Metal Progress, 1939, vol. 36, Nov., pp. 633–635, in which a method of welding galvanised sheets with a tin-coated copper-silicon filler rod is described. (*See* Journ. I. and S.I., 1940, No. I., p. 150 A).

The Welding of Light Gauge Steel. S. G. P. de Lange and E. S. Waddington. (Welding Industry, 1940, vol. 8, May, pp. 124–130 ; June, pp. 147–151). The authors describe and illustrate the principles to be followed for the successful arc- and resistance-welding of sheet metal and give advice on the technique to be adopted.

Welding in the Design and Construction of Industrial Plants. A. S. Low. (Welding Journal, 1940, vol. 19, May, pp. 329–338). The author describes how the Austin Co., Cleveland, Ohio, developed electric welding in their fabricating shops and the advantages which resulted, the most important of which were the saving in weight of steel members and the saving in the time required for erection. A noteworthy feature of the company's welding shop is that the generating sets are carried in suitable frames suspended from a monorail fixed to the roof supports. Descriptions and illustrations of many large welded-steel factory buildings are presented.

Stress Control Without Preheating. F. F. Mooney. (Welding Journal, 1940, vol. 19, Apr., p. 269). The author describes the application of a special technique to the welding of fractured cast-iron pulleys or gears. In certain suitable cases the technique consists of making a hack-saw cut in the casting, the position of which is chosen so that, first, the cut will close up on welding the fracture, thus taking up the expansion, and secondly, the cut is sufficiently close to some massive part of the casting to conduct away the heat applied when welding the cut. In the case of a fractured rim, a jack is employed to force open the fracture about $\frac{1}{16}$ in. before welding and the joint is allowed to cool with the jack removed.

Welds and the Testing of Their Endurance. J. H. Hruska. (Iron Age, 1940, vol. 145, May 16, pp. 33–37). The author describes a method of making fatigue tests on specimens of welded joints in steel plate. The specimens are cut to a special shape with a milling cutter and some are subjected to dynamic tests at the rate of 1750 bending reversals per min., whilst others of exactly the same dimensions are subjected to a series of static loads, from the results of which the static bending stresses can be calculated. The results obtained by these dynamic and static tests enable the expected performance of the welds to be estimated with fair accuracy.

The Formation of Cracks after Welding. B. Bochenek. (Aircraft Engineering, 1939, vol. 11, Nov., pp. 428–430). The author

discusses the causes of the occurrence of minute cracks in chromium-molybdenum and chromium-manganese-silicon steels after welding with the oxy-acetylene flame. It is noted that electric welding does not cause this type of cracking. He refers to Werner's experiments, which showed that steels rather high in carbon and sulphur, produced in an electric furnace, were prone to this defect. In the author's opinion this cracking tendency is to a great extent dependent on the stresses remaining in the metal immediately before the welding operation—*i.e.*, those induced by rolling, bending or other forming operations.

British Standard Methods of Testing Fusion Welds, Welded Joints and Weld Metal. (Applicable to the Electric Arc Welding of Steel). (British Standards Institution, No. 709, revised 1940). In this specification of tests for electric welds, joints and weld metal, the more important tests are standardised and co-ordinated and a general indication is given of the purpose served by each of the different standard tests.

Definitions of Welding Terms. (Welding Journal, 1940, vol. 19, Apr., pp. 270–279). A list of definitions of welding terms with explanatory diagrams is presented. These definitions have been prepared by the Committee on Definitions and Chart of the American Welding Society, and they have been approved by the Executive Committee of this society as " tentative."

Oxygen Cutting of Steel. Part II. Oxygen Cutting Procedure. W. Spraragen and G. E. Claussen. (Welding Journal, 1940, vol. 19, May, Supplement, pp. 161–206). The authors complete the review of the literature to January, 1939, on the autogenous process of cutting steel (*see* Journ. I and S.I., 1939, No. II., p. 278 A). In this part they deal in turn with the factors affecting the cutting speed ; the influence of impurities in the gases used ; the use of hydrogen, town gas and propane ; when preheating is necessary ; procedures for cutting holes and overhead cutting ; and, finally, costs. A bibliography of 333 references is included.

How to Cut Chromium Steel Castings. R. B. Aitchison. (Welding Journal, 1940, vol. 19, May, pp. 325–328). The author describes the technique for oxy-acetylene cutting risers from chromium-steel castings. Straight chromium steels with up to about 14% of chromium are air-hardening, and those containing 15–20% of chromium are slightly air-hardening, whilst the 18/8, 25/12 and 25/20 chromium-nickel austenitic steels are not air-hardening. Castings of the first two groups must therefore be preheated before commencing to cut off the risers, whilst those of the last group may be cut at room temperature. The carbon content is also very important ; with more than about 0·30%, preheating is necessary, and the whole of the casting must be heated to about 900° F. Also more slag is formed and it is less fluid than that occurring in the cutting of mild steel, so that a higher oxygen pressure is necessary.

MACHINING

How Gases and Oxides Affect Machinability. G. T. Motok. (Steel, 1940, vol. 106, Apr. 29, pp. 62–63, 75). The author reports on an investigation of the causes of wide variations in the machinability of a number of steel crankshafts of identical chemical analysis as obtained by routine methods. It had been found that the number of shafts which could be machined before regrinding the cutting tool varied between 30 and 100. The tests made included vacuum-fusion determinations of gases and oxides, McQuaid-Ehn grain-size determinations, examination of macrographs and a study of the log of the steel-furnace procedure. It was found that the differences in the distribution of the gases and oxides were chiefly responsible for the differences in machinability. In the samples of steel with poor machining properties more iron oxide, manganese oxide and nitrogen were found towards the centre, and more silica and alumina towards the rim of the specimens.

Machining Hard Alloy Steels. (Steel, 1940, vol. 106, May 27, pp. 74–75). Some examples are given of the application of steel S.A.E. X-4340 for aeroplane engines and other engine parts which have to be machinable even after heat treatment. The composition of this steel is : Carbon 0.35–0.45% ; manganese 0.50–0.80% ; nickel 1.50–2.00% ; chromium 0.60–0.90% ; and molybdenum 0.20–0.30%. The examples demonstrate that this steel, even when heat-treated to produce a hardness of 450 Brinell, can be machined with tools of 18/4/1 tungsten-chromium-vanadium high-speed steel.

What It Takes to Turn Stainless. (Machinist, 1940, vol. 84, May 25, pp. 195–198). A description is given of the machining practice developed in the course of fifteen years of experience in the manufacture of stainless steel parts for bottle-filling machinery. Drawings are given showing the correct design of lathe and automatic tools, drills, reamers and taps, and recommendations regarding procedure and the coolant are made.

Lead-Bearing Steels; Control of Possible Health Hazard during Fabrication. J. W. Halley and E. D. Martin. (Metal Progress, 1940, vol. 37, Apr., pp. 412–418). The authors describe some investigations made with the object of determining whether a dangerous amount of lead is released to atmosphere during the processes of welding, cutting and forging Ledloy steel which contains about 0.25% of lead. The results showed that there is no danger to health in the handling, machining, heat-treating and ordinary

forging of Ledloy steel. If, however, it is to be welded or flame-cut, calculations should be made to determine whether lead concentrations above the safe limit will develop. (The limit suggested by the authors is 3 mg. of lead in 10 cu. m. of air.) In cases where additional ventilation is required the amount of air to be moved is small and only inexpensive equipment is required.

Conditions for Drilling Holes with Hard-Alloy-Tipped Twist-Drills. N. I. Orlov. (Vestnik Metallopromyshlennosti, 1939, No. 5, pp. 56–64). (In Russian). After some general remarks on drilling, the author presents data in the form of curves and tables of suitable feeds, cutting speeds, drilling force, turning moments and power requirements for hard-alloy-tipped drills, and finally gives some general hints on their use and care. Some general expressions for calculating the above figures are given, and test data obtained on different grades of cast iron are presented.

Cutting Fluids. A. H. Lloyd and H. H. Beeny. (Canadian Metals and Metallurgical Industries, 1940, vol. 3, Apr., pp. 97–99). The authors examine the problem of selecting a suitable coolant for modern lathes and machine tools and describe a form of drip test for determining the corrosive action of these liquids. For this test a block is made from metal similar to that used for lathe beds and a number of recesses are formed in it with a milling cutter ; small piles of brass and steel chips are put in each recess to simulate workshop conditions ; samples of the coolants to be tested are placed in beakers and allowed to drip very slowly over the chips, one coolant to each recess. The test is usually run for three or four days, after which the degree of corrosion in each recess is examined. The authors also describe a cutting fluid for use on heavy modern lathes. It is slightly alkaline when mixed with water and the emulsion is such that the oil is suspended in a condition corresponding to a true solution ; the liquid is clear or opalescent, not milky, when first put into use. The emulsion is very stable, which enables high dilutions to be used. Two years of practical experience have shown that this is an excellent cutting fluid.

CLEANING AND PICKLING OF METALS

Steel Conditioning with the Oxy-Acetylene Method. G. D. Winlack. (Iron and Steel Engineer, 1940, vol. 17, Apr., pp. 44–53). After a brief reference to the slowness and high cost of removing surface defects from billets by chipping and grinding, the author describes the development of deseaming or scarfing, which is the process of cleaning the surface of a billet by passing an oxy-acetylene flame over it. Although hand torches with single and multiple nozzles are used in some cases, scarfing machines have recently been developed with two heads, each of which consists of two banks of nozzles set at right angles. With such a machine all four sides of a bloom or billet can be scarfed in one pass at speeds of approximately 100 ft. per min.

The Gas-Scarfing of Surface Defects in Rolling. E. Shanovskiy and N. Kunitsyn. (Stal, 1939, No. 8, pp. 23–25). (In Russian). Some details of the scarfing of blooms with an oxy-acetylene burner developed at the Siberian Metallurgical Institute are described and the results are compared with those obtainable by pneumatic chipping. The nozzle of the burner has a central opening for the oxygen cutting stream and a number of concentrically-placed small openings for the acetylene flame. The various numerical results indicate that gas-scarfing is about five or six times as efficient as chipping and can remove such serious defects as tears and folds. The removal is also much more thorough. The danger of " digging in " when using the burner carelessly is mentioned. Gas-scarfing can be cheaper than the mechanical method, and it is possible that the gas consumption may be reduced still further by appropriate choice of nozzles. The surface produced is satisfactory.

A Chemical Polishing Method. A. L. Field and I. C. Clingan. (Steel, 1940, vol. 106, Apr. 22, pp. 54–56, 64). The authors describe an electrochemical process of polishing which consists essentially of making the article to be polished the anode in an electrolyte composed of citric acid (30–70% by weight), sulphuric acid (10–30%) and the balance water. The temperature of the bath is 180–190° F., and a current density of 0·5–1·5 amp. per sq. in. of surface is used according to the size of the article and its surface condition. The process has been found very suitable for wire products, in particular for refrigerator shelves.

Comments on Electrolytic Polishing of Metals. H. Pray and C. L. Faust. (Iron Age, 1940, vol. 145, Apr. 11, pp. 33–37). After briefly reviewing the literature on the electrolytic polishing of ferrous

and non-ferrous metals, the authors describe the mechanism of the process, pointing out the essential differences between electrolytic and mechanical polishing.

Pickling and Polishing of Metals. S. Tour. (Iron Age, 1940, vol. 105, May 23, pp. 56–60 ; May 30, pp. 26–30). In the first part of this article the author reviews the patents and some of the technical literature published since 1915 on those processes of pickling and polishing metals which are based on electrolysis. In the second part he describes the Blaut-Lang process patented in America in 1938. This process is applicable to all types of stainless steel and to a number of non-ferrous metals and alloys ; the bath used contains a mixture of phosphoric and sulphuric acids. The author also gives details of a series of comparative tests using the following seven processes : (1) The Blaut-Lang process ; (2) that of the Allegheny Ludlum Steel Corporation (see G. Kiefer's paper, Journ I. and S.I., 1940, No. I., p. 246 A) ; (3) Burns and Warner's patent ; (4) Fink and Kenny's patent ; (5) Kelvie's patent ; (6) Larsen's patent ; and (7) Marino's patent. He states that some interesting differences were observed but does not give details of the results obtained.

Pickling of Steel for Chemical and Allied Industries. G. H. Challis. (Industrial Chemist, 1940, vol. 16, May, pp. 154–157). The author describes a pickling process which consists of immersing the steel in a 3–6% sulphuric acid solution at 65° C., dipping twice in water held at 65° C. and immersing for 3–5 min. in a 2% phosphoric acid solution held at about 85° C. The author also recommends that a priming coat of paint be applied, if possible, immediately after pickling while the material is still warm. This process is particularly suitable for steel plates for large tanks used for the storage of petroleum products.

Heating Solutions. D. Augsburger. (Steel, 1940, vol. 106, Apr. 22, pp. 46–49). The author discusses the use of steam jets and heat-exchangers for the heating of pickling and plating solutions and gives examples of the applications of each. He describes and illustrates two types of heat exchanger with 2·5 and 14 sq. ft. of effective surface, respectively, and presents a number of graphs showing the rate of heat transfer per hour in relation to the steam pressure for different rates of pumping of the solution through the exchanger. In conclusion he considers some of the alloys suitable for resisting the corrosion of the solutions used, with special reference to " Duriron," an alloy containing about 14·5% of silicon.

The Disposal of Waste Acids. W. W. Hodge. (Wire and Wire Products, 1940, vol. 15, Jan., pp. 32–42). The author surveys the methods of treating and disposing of waste pickle liquor.

COATING OF METALS

The Theory of the Potential and the Technical Practice of Electro-deposition. Part II. Point-Plane and Line-Plane Systems. C. Kasper. (Electrochemical Society, 1940, Apr., Preprint No. 28). Continuation of a series of papers on the theory of electric potential (*see* p. 21 A). The author considers the flow of electricity through an electrolyte from a point electrode and from a line electrode to an infinite-plane electrode, and explains methods of calculating the potential in each case.

Cadmium Plating. A. Bregman. (Iron Age, 1940, vol. 145, Apr. 18, pp. 36–40). The author reviews the development of cadmium-plating in America, gives numerous examples of its application and compares the properties of cadmium coatings with those of other metals. He also gives some cost data for producing deposits on a commercial scale.

Aluminising Process. Protection of Metals Exposed to Elevated Temperatures. L. E. Kunkler. (Metallizer, 1940, vol. 8, May, pp. 3–5, 10). The author describes and illustrates a process of spraying aluminium on to iron or steel, the object of which is to prevent the formation of scale when the steel is used at temperatures up to $1000°$ C. This process is usually known as " aluminising," and the coating may be said to consist of three layers: (*a*) A solid solution of iron and aluminium fused on to the steel; (*b*) a layer of the alloy $FeAl_3$ with a slight excess of free aluminium; and (*c*) a thin coating of aluminium oxide. To prevent oxidation of the aluminium after the spraying, the part is subjected to a sealing treatment; this consists of brushing on, or dipping in, water-glass and heating the part to $1850°$ F. for 10 min. and cooling in still air.

Surface Protection by Aluminium, with Especial Reference to Coatings Produced by Spraying. W. Schnorrenberg. (Aluminium, 1940, vol. 22, Mar., pp. 149–151; Apr., pp. 205–209). The author reviews the various methods used for the production of aluminium coatings, including coatings on steel and on ordinary and malleable cast iron. He refers in particular to coatings produced by spraying and discusses their properties at some length.

The Use and Application of Fuel Oil for Heating the Galvanizing Kettle. W. G. Hartman. (American Hot Dip Galvanizers Association : Wire and Wire Products, 1940, vol. 15, Apr., pp. 215, 218–220). The author discusses the fuel costs and the experience gained when using a vaporised fuel-oil distillate for heating a galvanising kettle 22 ft. 6 in. long, 28 in. wide and 48 in. deep, at the Minneapolis Works of the Lewis Bolt and Nut Co.

Straight-Line Sheet Galvanizing. D. A. McArthur and R. A. Gender. (Iron Age, 1940, vol. 145, Apr. 11, pp. 38–41). The authors describe a number of straight-line galvanising units recently installed at the Steubenville Works of the Wheeling Steel Corporation. They pay particular attention to the methods of controlling the speed at which the sheets pass through the various units in the line, as proper synchronisation is most important.

Hot Dip Galvanizing. H. R. Hanley. (Metal Progress, 1940, vol. 37, Apr., pp. 431–435). The author reviews the present position of the development of hot-dip galvanising and discusses the factors affecting the adherence of the coating, its thickness, appearance, strength and resistance to corrosion.

How Durable are Hot-Dip Zinc Coatings? W. G. Imhoff. (Products Finishing, 1940, vol. 4, May, pp. 24–36). The author explains, for the benefit of the buyer of galvanised sheets, some of the conditions of manufacture which must be complied with in order to ensure that the sheet will give good service for a long period.

On the Hot-Dip Zinc Coatings of Welded Gas Pipes. Y. Ogino. (Tetsu To Hagane, 1940, vol. 26, Mar. 25, pp. 164–173). (In Japanese).

The Streaking of Hot-Galvanised Sheets. (Iron and Coal Trades Review, 1940, vol. 140, June 14, p. 883). Some notes are presented relating to Rädeker's investigation of the causes of fluting or streaking on the surface of galvanised sheets. This may be caused by the formation of a thick skin of alloy on the sheet due either to the accumulation on the surface of grains of cementite under the scale of the sheet or to an excessive reduction in the concentration of aluminium in the galvanising bath. The presence of aluminium has an important influence on the attack of molten zinc on steel ; with high-carbon steels the formation of hard zinc is reduced when the aluminium concentration of the bath is raised. The work of Rädeker and Haarmann on the character of the attack of zinc on steel is also discussed (*see* Journ. I. and S.I., 1940, No. I., p. 157 A).

American Hot-Dip Tinning Practice. 2. Electrically Heated Hot-Dip Tinning Furnaces. W. G. Imhoff. (Metal Industry, New York, 1940, vol. 38, Apr., pp. 201–202). The author describes and illustrates some electrically heated tinning equipment for the tinning of small forgings, refrigerator parts, &c., by the hot-dip process. He stresses the importance of using good-quality soft tin and of having temperature-recording instruments combined with means of accurate temperature control.

Local Variations of Coating Thickness of Tinplate. B. Chalmers. (Sheet Metal Industries, 1940, vol. 14, June, pp. 619–620). The author refers to the development of a satisfactory instrument (the Salford Layer Thickness Meter) for the non-destructive measurement of the thickness of tin on tinplate which measures the thickness at points instead of over a considerable area. In the present paper he briefly describes an investigation of the extent to which local

variations in thickness affect the use of the new instrument. The method adopted was to take large numbers of readings at points chosen at random on a series of typical specimens of ordinary commercial tinplates; distribution diagrams were then drawn in which the number of times any given reading occurred was plotted against the value of the reading. From these curves it is possible to calculate the " standard deviation," which shows how far any value is likely to be removed from the true or average figure.

Measurement of Tinplate Coating. B. Chalmers. (Iron and Coal Trades Review, 1940, vol. 140, June 7, p. 854). The author refers to an electromagnetic method of measuring the thickness of tinplate coatings on steel which has been described previously (*see* Journ. I. and S.I., 1938, No. I., p. 135 A). This method gives consistent results as long as the magnetic properties of the steel base are unchanged. In the present paper he describes a modification of the instrument which takes into account any variation in the properties of the steel base. The principle of the new method is that an independent measurement of the magnetic properties of the steel is made at the same locality as the coating thickness measurement and a correction is automatically applied to the measurement as made by the original method.

The Problem of Determining the Thickness of Corrosion-Resisting Coatings. N. S. Akulov. (Vestnik Metallopromyshlennosti, 1939, No. 9, pp. 78–80). (In Russian). A simple pocket instrument of the magnetic type has been constructed for measuring the thickness of non-magnetic coatings on steel. The force required to pull the poles of the magnet from the surface is automatically recorded by the instrument. A high sensitivity, variable within wide limits, and a linear scale are special features of the instrument.

Some Principles of the Enamelling of Cast Iron. G. T. O. Martin. (Institute of British Foundrymen and Institute of Vitreous Enamellers : Foundry Trade Journal, 1940, vol. 62, Apr. 4, pp. 260–264 ; May 2, pp. 331–334). The author considers three factors which affect the quality of enamelled iron castings ; these are (*a*) the effect of the metal ; (*b*) the effect of the enamel ; and (*c*) the effect of the application process.

Wet-Process Leadless Cast-Iron Enamels. B. Niklewski, jun., and A. I. Andrews. (Journal of the American Ceramic Society, 1940, vol. 23, June, pp. 178–185). With a view to developing better leadless enamels for use on cast iron, the authors have experimented with many frit mixtures. They found that such enamels for application without a ground coat must be high in boron trioxide and low in sodium oxide. The presence of a high percentage of barium oxide, zinc oxide and calcium oxide had a good influence on the firing range of this enamel, but the amount was limited by the tendency to crystallise. The addition of fluorspar up to 11% was necessary to produce good workability, but cryolite was undesirable as it tended to produce opacity.

PROPERTIES AND TESTS

Photoelasticity as Applied to Design Problems. O. J. Horger and T. V. Buckwalter. (Iron Age, 1940, vol. 145, May 23, pp. 42–50). The authors describe and illustrate the optical equipment in the laboratories of the Timken Roller Bearing Co., which is used for making photo-elastic investigations of stresses in metals. They explain the details of the process and give several examples of its application in the study of bearing design and the strength of screw-threads in bolts, nuts and studs.

The Impact Test. V. I. Garcia and S. Gerszonowicz. (Revue de Métallurgie, Mémoires, 1940, vol. 37, Mar., pp. 86–92 ; Apr., pp. 117–122). This is a French translation of a Spanish publication in Bulletin No. 6 of the Technical School of Montevideo, issued in July, 1938. The authors publish the replies which they received from a large number of investigators of many countries in response to a questionnaire containing nineteen points of importance in connection with the impact test. In conclusion the authors express their own views on these points.

The Possibility of Replacing Prismatic by Cylindrical Impact Test-Pieces. G. N. Titov. (Zavodskaya Laboratoriya, 1939, No. 12, pp. 1297–1298). (In Russian). Some experimental results on normalised 0·53% carbon steel rod indicated that the cylindrical specimens provided with a rounded circumferential groove as used by the author gave values for impact strength agreeing very well with those obtained with standard Mesnager test-pieces of the same steel at ordinary temperatures. The two sets of results tended to deviate slightly at low and at elevated temperatures.

The Notched Bar Test. O. R. J. Lee. (Journal of the Institution of Mechanical Engineers, 1940, vol. 143, June, pp. 114–120). The author discusses some results obtained when investigating the effects of variations in the width of the specimen, the notch radius, the notch depth, the velocity of testing and the temperature of testing on the specific impact strength of steel specimens. He quotes Stribeck's results, which showed that when the width of the specimen was less than 15 mm., consistent high values of specific energy were obtained with fibrous fractures ; specimens wider than 25 mm. gave low but apparently consistent values of specific energy and broke with a crystalline " brittle " fracture ; specimens 15–25 mm. wide gave very inconsistent results. Specimens of 0·2% carbon steel showed a change from tough to brittle behaviour with a notch of 1 mm. radius ; in the tough condition this steel gave a slowly increasing specific energy with increasing notch radius.

With regard to notch depth, Dupuy, Mellon and Nicolau's systematic investigation showed that for brittle behaviour the notch depth had no influence on the specific energy, whilst for tough behaviour, as the notch depth was increased, the specific energy slowly decreased at a slightly diminishing rate. Docherty demonstrated that as the testing velocity was increased there was a gradual increase in the amount of energy absorbed by the specimen. The influence of changes in the testing temperature on the specific energy is clearly brought out by constructing energy-temperature curves ; at temperatures just below atmospheric the " cold-brittleness " occurs, whilst at a blue heat the drop in notched-bar impact values indicates blue-brittleness. The cold-brittleness represents a change from tough fibrous fracture to brittle crystalline fracture and is not due to any change in the structure or work-hardening capacity of the material.

Ageing of Unalloyed Iron and Steel. B. Steenberg. (Jernkontorets Annaler, 1940, vol. 124, No. 2, pp. 41–67). (In Swedish). The author presents a very comprehensive survey of the literature on the ageing of iron and steel with a bibliography of 153 references.

Galvano- and Thermomagnetic Phenomena in Iron and Nickel. E. H. Butler, jun., and E. M. Pugh. (Physical Review, 1940, vol. 57, May 15, pp. 916–921). The authors describe how four transverse galvanic and thermomagnetic effects (the Hall, Ettingshausen, Nernst and Righi-Leduc effects), the Thomson coefficient, and the thermal and electrical conductivities were measured in bars of nickel and electrolytic iron. The authors also verify the three independent relations between the effects, which were derived by Sommerfeld on the basis of the Fermi statistical theory of metallic conduction. They show that this theory does not account for the magnitude of an individual effect unless the average field for the conduction electrons in the iron is twice the measured value of the magnetic induction, and unless in the case of nickel it is about fifteen times the magnetic induction. They put forward two possible explanations of this.

Magnetic and Electrical Methods of Control of Piston Rings. T. D. Kubyshkina. (Zavodskaya Laboritoriya, 1939, No. 12, pp. 1268–1272). (In Russian). Using a differential magnetic induction method, a comparative electrical-resistance method, and an absolute electrical-resistance measuring method with a Thomson bridge, the author investigated whether it was possible to relate any of these measurements to the structure and hardness of piston rings. After tests on multiple-, centrifugally and individually cast rings, he found that the electrical-resistance method of grading was suitable for the individually cast rings in which appreciable variation in the size of the graphite flakes is possible. The method was not applicable to multiple-cast rings in which the variation in the size of the graphite is much less. The magnetic method can be used for detecting cementite. It was confirmed that the hardness of rings does not provide a reliable indication of their structure.

Cast Iron and Its Relation to Machine Tools. P. A. Russell. (Journal of the Institution of Production Engineers, 1940, vol. 19, Apr., pp. 129–139). After enumerating those properties of cast iron which render it a suitable material for constructing the main parts of machine tools, with special reference to wear resistance, the author discusses the results of some hardness tests on 2-in. bars of " Shorterised " (a process of flame-hardening) and machine-tool cast irons as well as on some nickel-chromium irons. In conclusion he refers to some results of machinability tests with a number of special cast irons, including a white martensitic iron with a hardness exceeding 500 Brinell, and on Ni-Tensyl, Ni-Hard and Silal cast irons.

The Extended Uses of Cast Iron, with Special Reference to War Conditions. J. G. Pearce. (Institute of British Foundrymen, June, 1940, Paper No. 709 : Foundry Trade Journal, 1940, vol. 62, June 13, pp. 437–438). The author suggests making additional use of cast iron for a large variety of purposes with the object of releasing steel and non-ferrous metals for essential applications the requirements of which do not permit of the substitution of any other material. In an appendix a list of a large number of extended uses of cast iron is presented.

High Tensile Steel for Structural Purposes. H. E. Wright. (Proceedings of the Cleveland Institution of Engineers, 1939–40, No. 4, pp. 133–163). The author describes some stages of the development of high-tensile steel for bridge building and structural work which led eventually to the publication, in 1934, of British Standard Specification No. 548 for high-tensile structural steel. He classifies these steels into the four following groups : (1) The so-called silicon steel of American origin ; (2) steels which rely largely on manganese to give a yield point of 23 tons ; (3) the same steels as in (2), but containing 0·25–0·5% of copper ; and (4) steels which rely upon the addition of chromium, copper and manganese and are more resistant to corrosion than those of group (3). Both Great Britain and Germany produce types of high-tensile steel to comply with standard specifications, and although a variety of elements is used in such alloy steel, the author's method of grouping covers nearly all the types in use, and the author's experience is that alloy steels containing about 0·25% of carbon or less are, on the whole, preferable to those which rely upon a carbon content approaching the maximum of 0·3%. Provided that the alloy steels are low in carbon, they present no more difficulty in fabrication in a modern constructional plant than mild steel so far as normal cold-shearing, punching, cutting and machining operations are concerned. The author also discusses the corrosion resistance, weldability and impact resistance of high-tensile steels.

Metals as Engineering Materials. C. H. Desch. (Three Cantor Lectures, Feb., 1940 : Journal of the Royal Society of Arts, 1940, vol. 88, May 17, pp. 591–632). The first of these lectures is historical in character ; in it the author traces the development of methods of

working metals from the Bronze Age onwards. He shows that the metallurgical inventions of Darby, Huntsman and Cort made possible the machines of Arkwright and Watt, which in turn brought about the Industrial Revolution. The processes of Bessemer and Siemens inaugurated the age of modern machinery and large-scale steel structures. The introduction of alloy steels made possible the development of aircraft. From this sequence of events it is seen that a metallurgical revolution preceded each mechanical revolution. In return, the stimulus given by engineering developments to research in metallurgy has been very great. In the second lecture the author discusses the properties and methods of testing metals, considering in turn tensile, creep and fatigue tests, corrosion-fatigue, wear and age-hardening, and pointing out the limitations of the various tests and the errors to be avoided in applying test data to design. In the third lecture the author deals with the effects of additions of alloying elements to iron and steel as well as to some of the non-ferrous metals, and he concludes with some remarks on recent applications of alloys prepared by the process known as " powder metallurgy " or " metal ceramics."

Design of Test-Pieces for Carbon Steel Castings. C. H. Kain and E. W. Dowson. (Institute of British Foundrymen, June, 1940, Paper No. 710 : Foundry Trade Journal, 1940, vol. 62, June 13, pp. 435–436). The authors consider the freezing phenomena of test-blocks designed for the provision of test-pieces for steel castings. They suggest rules governing the design of an ideal test-block of clover-leaf section and present data is support of this design.

" Tailor-Made " Steels. T. Grey-Davies. (Sheet Metal Industries, 1940, vol. 14, Apr., pp. 396–398). Continuation of a series of articles (*see* p. 100 A). (*Note* : Although the previous article was referred to as Part XVI., the present one is numbered XIV. in the above publication.) The author discusses the effects of variations in the amounts of carbon, manganese, molybdenum and tungsten in steel on the properties of finished steel sheets.

Molybdenum-Vanadium Steels as Substitutes for High-Speed Steel. M. P. Braun, A. M. Vlasov and R. I. Evenbakh. (Vestnik Metallopromyshlennosti, 1939, No. 9, pp. 34–39). (In Russian). The authors examined the response to heat treatment and the cutting properties of three molybdenum-vanadium steels (two containing tungsten) and compared their properties with those of 18/4/1 tungsten-chromium-vanadium tool steel. The analyses of the three steels were as follows :

						(1) %	(2) %	(3) %
Carbon	.	.	.	.	.	1·11	1·24	1·52
Manganese	.	.	.	.	.	0·43	0·24	0·72
Silicon	.	.	.	.	.	0·28	0·32	0·25
Chromium	.	.	.	.	.	4·20	4·02	4·25
Molybdenum	.	.	.	.	.	4·27	4·20	3·73
Vanadium	.	.	.	.	.	3·03	4·04	4·10
Tungsten	.	.	.	.	.	...	5·55	3·81

The steels were prepared in a basic-lined H.F. furnace and cast into 25-kg. ingots which were then forged at 1100–900° C., annealed and cooled in air. Optimum heat-treatment schedules were worked out on the basis of the results of hardness tests and microscopic examinations. Tool tips made of the three steels were tested by machining steel blanks with hardnesses in the range 163–217 Brinell. It was found that the most suitable heat treatments were as follows : (a) Steel (1), quenched from 1240° C. and double tempered at 520° C. ; (b) steel (2), quenched from 1240° to 1270° C. and double tempered at 520° C. ; and (c) steel (3), quenched from 1240° to 1270° C. and triple tempered at 500–540° C. The authors noted that steel (3) was superior to ordinary high-speed steel for machining steel with a hardness of 329 Brinell, and that all three steels were considerably cheaper than the standard 18/4/1 tungsten-chromium-vanadium high-speed steel.

Low-Alloy High-Speed Steels. O. S. Ivanov. (Vestnik Metallopromyshlennosti, 1939, No. 9, pp. 23–33). (In Russian). The author reviews, mainly in tabular and graphical form, the chemical compositions, heat treatments and cutting properties of fifteen low-alloy high-speed tool steels which have been suggested for production purposes and discusses their relative merits. They all contain chromium which in some cases is as high as $10–13\%$. The presence of this element in this or lower proportions, with additions of molybdenum and vanadium and, in a few cases, silicon, eliminates the need for tungsten additions. The high chromium content tends to cause a large amount of austenite to be retained after quenching. This has a special bearing on the correct quenching temperatures, which frequently approach closely to the incipient melting temperatures, as well as on the application of repeated tempering. As a result of the critical examination of the available data, the following compositions are recommended for use as high-speed steels :

Russian classification :	EI172.	EI184.	EI260.	1303.
Carbon %.	0·9–1·0	0·9–1·02	0·9–1·02	0·9–1·02
Chromium %.	9·0–10·0	7·5–8·3	4·5–5·3	7·5–8·3
Vanadium %.	2·0–2·5	1·0–1·5	2·0–2·5	1·0–1·5
Tungsten %.	...	4·0–5·0	...	...
Molybdenum %.	...	...	3·5–4·0	3·5–4·0
Rockwell hardness	C62	C63	C64	C63

It is claimed that steel *EI*260 is suitable for all purposes for which high-speed steel is used.

Oil-Hardened and Tempered Manganese Steels. (Metallurgist, 1940, vol. 13, June, pp. 114–116). A table is presented giving the analysis, application, tensile strength, yield point, elongation and reduction of area of eleven different manganese steels, all oil-hardened, except one, and tempered. This table shows that there is available a variety of steels containing between $0·50\%$ and $1·70\%$ of manganese, with a range of tensile strength of 40–70 tons per sq. in., having good yield points and acceptable values of elonga-

tion, reduction of area and impact strength, which are suitable substitutes for chromium-molybdenum steels.

Thermo-Electric Method of Classifying Steels. G. V. Akimov and L. E. Pevzner. (Zavodskaya Laboratoriya, 1939, No. 12, pp. 1273–1282). (In Russian). The authors describe some preliminary investigations of the thermo-electric e.m.f. produced with thermocouples made up from a number of standard Russian plain and low-alloy steels. The effects of changes in chemical composition and heat treatment of the steels and of the temperature of the hot junction were observed, the object being to work out, if possible, a method of classifying steels by the e.m.f. produced. They describe two types of instrument which were successfully used for the routine classification of certain steel compositions.

Control of Steel Composition and the Problem it Presents. E. C. Smith. (American Iron and Steel Institute, General Meeting, May, 1940, Preprint). After a brief survey of the various steel-making processes used in the United States the author observes that the demands of users of steel coupled with the research work of steel manufacturers has led to the development of about 5000 different specifications for steel. He then argues the case for a drastic reduction in this number of specifications which he regards as one of the causes of the alternating periods of boom and slump in the industry. He suggests that some economic inducement should be offered to buyers to consume more of the standard rather than the special products of the steelmaker ; conversely, any specification which is so rigid that more than 10% of the heats of steel made in an efficiently operated basic open-hearth furnace do not pass inspection should be considered as unsatisfactory, and the buyer demanding such a steel should be made to pay a high price for it.

The New Research Laboratories of High Duty Alloys, Limited. (Foundry Trade Journal, 1940, vol. 62, May 9, pp. 347–349). **The Research Laboratories of Messrs. High Duty Alloys, Limited.** (Engineering, 1940, vol. 149, May 10, pp. 481–482). **New Metallurgical Research Laboratories.** (Engineer, 1940, vol. 169, May 10, p. 439). **The New Laboratories of High Duty Alloys, Limited.** (Metallurgia, 1940, vol. 22, May, pp. 1–4). **Light Alloy Research.** (Aircraft Production, 1940, vol. 2, July, pp. 227–230). An illustrated description is presented of the new research laboratories of High-Duty Alloys, Ltd., at Slough. The building includes separate laboratories for the following classes of work : Spectrography, corrosion and protection, X-ray crystallography, damping, colorimetry, experimental testing, metallography, chemistry, experimental heat treatment and rolling, experimental founding, and mechanical testing.

METALLOGRAPHY AND CONSTITUTION

The Iron-Plating of Specimens for Microscopical Examinations. E. A. Jenkinson. (Iron and Steel Institute, 1940, this Journal, Section I.). This paper gives an account of a method of supporting fractured surfaces of creep and tensile test-pieces so that longitudinal sections can be prepared for microscopical examination right up to the fracture. After a brief discussion of the disadvantages of, first, a fusible-alloy mounting and then a thick copper electrodeposit, experimental work on the production of heavy electrodeposits of iron with suitable qualities is described. The general effect of temperature and current density on the microstructure of the plating is illustrated by micrographs. It has been found possible to obtain suitable deposits when employing a temperature of 85° C. and current densities between 5 and 20 amp. per sq. ft.

The Detection of Defects in Magnetic Materials by Magnetic Methods. A. M. Armour. (Metropolitan-Vickers Gazette, 1940, vol. 18, June, pp. 424–432). After briefly explaining the principles of magnetic crack detection, the author describes the magnetic-needle method, the magnetic-powder method and the magnetic-fluid method. He next describes the methods of magnetisation and some of the testing instruments and appliances for examining large and small articles. In conclusion he explains that it is also necessary to demagnetise an article after testing it to prevent the collection of particles which cause accelerated wear.

Soviet High-Speed " Defectoscope " for Rails. A. Gorelik, V. Smirnov and S. Samarin. (Vestnik Metallopromyshlennosti, 1939, No. 9, pp. 76–78). (In Russian). A brief description is given of an apparatus called a " defectoscope " which is used for detecting faults in rails. It can be moved over the rails at a speed of 10–25 km. per hr. It incorporates horse-shoe electromagnets, and any local variation in the magnetic field caused by either internal or external defects in the rail head induces currents in a search coil which are amplified and recorded. A wiring diagram of the apparatus is also given.

The Crystal Structure of Cementite, Fe₃C. H. Lipson and N. J. Petch. (Iron and Steel Institute, 1940, this Journal, Section I.). Previous workers on the structure of cementite have located the iron atoms accurately, but have failed to detect the carbon atoms. On the basis of space available, two alternative sets of sites are possible ; one of these is more probable, as it agrees better with the usual size of the carbon atom. By direct calculation of the electron

density in two different planes in the unit cell, using accurately measured intensities of X-ray reflection, the present authors have found the positions of the carbon atoms. They agree very well with the more probable of the two sets of positions previously suggested. A description of the structure is given, with a discussion of its possible relation to the structures of ferritic and austenitic iron.

Welding Metallurgy. Part V. Why Crystals Are Strong. O. H. Henry and G. E. Claussen. (Welding Journal, 1940, vol. 19, May, pp. 342–349). Continuation of a series of articles (*see* p. 71 A). In Part V. of this series the authors explain in simple terms the movement of atoms and crystals of which metals are composed during elastic and plastic deformation, the phenomena of slip and creep, the effects of heat and grain size on the strength of metals, and the relation of the appearance of a fracture to its cause.

Classification of Inclusions in Steel. (S.A.E. Journal, 1940, vol. 46, June, pp. 17–19). A method of classifying inclusions in steel developed by the Iron and Steel Division of the S.A.E. Standards Committee is described. The method was approved by the Iron and Steel Division in February, 1940, when it was recommended that the method should be published as a '' recommended practice '' before being submitted to the S.A.E. General Standards Committee for final adoption. The method specifies the way in which the specimen is to be cut and polished. The area to be examined is 1 in. $\times \frac{1}{2}$ in. The specimen is placed on the stage of a microscope and each individual field of the entire polished area is projected successively on a ground glass screen at 100 diameters. The ground glass is ruled with a series of parallel lines $\frac{1}{2}$ in. apart and this distance enables the inclusions to be measured in units of 0·005 in. A code of three symbols consisting of letters and figures has been worked out ; the first symbol indicates the length of the longest inclusion, the second indicates the average lengths of all inclusions other than the longest and over one unit in length, and the third indicates the '' background '' or the number of inclusions less than one unit in length, by reference to a standard classification A, B, C and D which represents four degrees of inclusion concentration as shown by the micrograph reproduced with the article.

Transformation in Manganese Steels. (Metallurgist, 1940, vol. 13, June, pp. 116–118). An abridged English translation is presented of Wever and Mathieu's paper on the transformations in steels containing 2% to 5% of manganese and carbon up to $1\cdot4\%$. This appeared originally in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 2, pp. 9–18. (*See* Journ. I. and S.I., 1940, No. I., p. 264 A).

Solubility of Nitrogen in Liquid Fe-Cr and Fe-V Alloys. R. M. Brick and J. A. Creevy. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1165 : Metals

Technology, 1940, vol. 7, Apr.). The authors report on some investigations which formed part of a programme of exploration into that part of the iron-chromium-nitrogen system which is stable at atmospheric pressure. They include the initial results of similar work on the iron-vanadium-nitrogen system. They found that the solubility of nitrogen in liquid alloys of iron and chromium increased in a slowly rising curve up to about 30% (atomic) of chromium and that a straight-line relationship existed above this percentage ; these results are in close agreement with those of Krivobok. The relation between solubility and pressure appeared to follow Sievert's square-root law. An increase in temperature lowered the nitrogen solubility. The solid iron-chromium-nitrogen alloys formed a eutectoid structure at some temperature below their melting points ; the nitrogen content of the eutectoid was about 8% by weight. Liquid chromium became saturated at atmospheric pressure at about 4% by weight of nitrogen, whereas solid chromium at 900° C. absorbed 13·7% by weight. Nitrogen lowered the freezing point of iron-chromium alloys but greatly raised the melting point of iron-vanadium alloys.

The Thermodynamical Analysis of the Liquidus Curves of Intermetallic Compounds. K. Hauffe and C. Wagner. (Zeitschrift für Elektrochemie, 1940, vol. 46, Mar., pp. 160–170). The authors develop equations which allow the calculation, based on the concentration, of the chemical potential of the liquid phase of an alloy, if the liquidus curve of an intermediately formed intermetallic compound is known.

CORROSION OF IRON AND STEEL

(Continued from pp. 73 A–74 A)

The Corrosion of Ferrous Metals. J. N. Friend. (Nature, 1940, vol. 145, June 8, pp. 881–883). In 1916 a committee was formed by the Institution of Civil Engineers to investigate the " Deterioration of Structures Exposed to Sea Water " and the investigation carried out by this committee consisted of exposing bars of fourteen different kinds of ferrous metal to the action of air, sea-water spray and total immersion at five ports offering a wide variation in climatic conditions. Three sets of bars have been exposed for periods of five, ten and fifteen years respectively. The results obtained after five and ten years' exposure have already been fully discussed in the Committee's Fifteenth Report (1935), but only numerical data on the fifteen-year tests have been published. In the present paper the author discusses a few of the more important practical conclusions to be derived from the results of all the tests. The full report of the committee has been held up owing to the war.

The Materials Corrosion Investigation at Eastport, Me. W. J. Jeffries. (Journal of the American Society of Naval Engineers, 1940, vol. 52, May, pp. 295–300). The author gives details of an investigation on the corrosion of materials commenced in 1936 at Eastport, Maine, in which nearly 700 specimens are under observation. All the materials are being tested in triplicate, one specimen in air, one in tidal water and one totally submerged. Seventeen classes of materials are under test, nine of which are non-ferrous, the remainder comprise : Cast iron, alloy iron, steel, cast steel, welded steel, alloy steel, chromium steel and chromium-nickel steel. Loss-in-weight determinations up to 1938 are presented diagrammatically to facilitate comparison. The exposure tests are still continuing and the author is not prepared to draw any conclusions yet.

French Investigations on the Protection of Metals Against Corrosion. E. Norlin. (Teknisk Tidskrift, 1940, vol. 70, May 11, pp. 197–203). (In Swedish). The author gives an account of long-time and short-time tests on the protective value of various coatings on a number of ordinary and alloy steel plates carried out at Bellevue near Paris by the two French committees working on this subject, namely, La Commission pour l'étude de la corrosion des produits métallurgiques and Le Comité des peintures et autres moyens de protection des matériaux.

Pitting of Stainless Steel. H. H. Uhlig. (American Institute of Mining and Metallurgical Engineers, Technical Publication No.

1150 : Metals Technology, 1940, vol. 7, Apr.). The author gives an account of his experimental investigation of the causes of the pitting corrosion of stainless steel. He examined in particular the following phenomena : (a) In sea water the pitting was more severe when the water was stagnant or polluted than in aerated, moving water ; and (b) pits once begun grew rapidly, usually becoming elongated in the direction of gravity. He comes to the conclusion that the pitting of stainless steel is caused by a breakdown in the passivity at local areas through electrolytic action where potential differences on the surface give rise to corrosion products at the focus of corrosion. The products of corrosion, which are mostly ferrous salts acidic in character (pH 1·4–2·0), have the property of destroying passivity and establishing a corrosion cell between passive and active metal, the difference in potential being about 0·5 V. The current then flows in greater magnitude and the rate of corrosion is accelerated ; the actual rate depends on the efficiency of depolarisation at the cathodic areas surrounding the anodes or pits. The incipient corroded area is limited in surface dimensions and tends to greater depth rather than breadth because of the non-corrosive character of the metal outside the pit, which is additionally protected by currents that limit the access of negative ions to the cathodic metal. In explanation of phenomenon (a) above, the author suggests that in aerated moving water the corrosion products do not accumulate, and the oxygen or oxidising solution diffusing to the attacked area will assist in re-establishing the passive state, thus preventing the extension of the corrosion. He explains phenomenon (b) by the movement and action of heavy corrosion products overflowing the pit and making contact with new areas of passive metal, destroying its passivity and establishing new corrosion cells, thus elongating the original pit. An abridged version of this paper appeared in Iron and Coal Trades Review, 1940, vol. 140, May 31, pp. 817–818 and June 7, pp. 847–848.   •

Microbiological Anaërobic Corrosion. H. J. Bunker. (Chemistry and Industry, 1940, vol. 59, June 15, pp. 412–414). The author explains the rôle played by bacteria in the promotion of the corrosion of iron and steel buried in soils and clays. He refers in particular to the action of *Vibrio desulphuricans* in reducing sulphates and to experiments described in one of his earlier papers (*see* Journ. I. and S.I., 1939, No. II., p. 46 A). In conclusion he emphasises that the sulphate-reducing mechanism is only one of several bacterial processes of a general type which are known to occur. For example, certain methane-producing organisms are responsible for reactions of this nature :

$$CO_2 + 8H \rightarrow CH_4 + 2H_2O.$$

This bacterial reaction takes place in association with the anaërobic fermentation of cellulose which is a common feature in boggy or

marshy ground.   Another example is the nitrate-reduction process which may be represented thus :

$$HNO_3 + 8H \rightarrow NH_3 + 3H_2O.$$
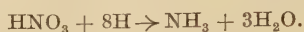
This reaction is not likely to occur in the case of buried pipe-lines, because these are usually laid below the depth at which nitrates occur in ordinary subsoils ; in systems such as tanks and gas-holders, conditions might arise when the possibility of this source of hydrogen-acceptor should be considered.

BOOK NOTICES

MIALL, STEPHEN. "*A New Dictionary of Chemistry.*" First ed. 8vo. Pp. xv + 575. London, 1940 : Longmans, Green and Co. (Price 42s.)

A technical dictionary must be about the most difficult kind of book to prepare. The chief characteristic of such a book is that the information is arranged in alphabetical instead of logical or chronological order, and while this makes it easy for the reader to find what he may be looking for, it makes it difficult for those who have to prepare the work. If the dictionary is to cover a wide field accurately and be completed within a space of time that prevents it getting out of date before it is finished, the co-operation of a team is required; this raises trouble for the editor, who has to fix the boundaries within which each contributor will work and also for each contributor, who keeps wondering what is being done by those whose fields are co-extensive with his own. By the selection of sufficiently well known authorities to attend to each aspect of the subject covered, it should be easy enough to ensure that the information is accurate, but it is obviously very difficult to ensure that numerous important entries are not left out through oversight on the part of the contributors or misunderstanding between them. A book like this is also difficult to review. It would be absurd to try to read it through, and, as its scope is so wide, most reviewers would find that they were able to check only a very small fraction of the contents. On the other hand, it would be unfair for a reviewer to choose certain words and look them up, then base his opinion of the book on the accuracy of the entries he found. Actually it appears that in reviewing a technical dictionary, the proper procedure is to indicate the ground covered and to assess the other characteristics of the work from consideration of the qualifications of those associated with it. In preparing the work the editor had the assistance of twenty-seven well-known chemists, each of whom, it may be certain, was able to ensure that his own entries were accurate. The preparation of the volume was divided among the teams, and, in addition to the major branches of chemistry, *i.e.*, organic, inorganic, physical and bio-chemistry, the work covers chemical engineering, crystallography, plastics and chemical biographies. In a brief foreword the late Sir Gilbert Morgan pays a tribute to the success that has been attained in meeting the need for a modern single-volume handbook on chemistry and the allied sciences in which the subject-matter is arranged alphabetically. Chemists are not the only people who have to look up information on chemical matters, and this work should be useful to doctors, physiologists, manufacturers, works managers, patent agents, lawyers and journalists. Although the arrangement is that of a dictionary, and a considerable amount of trouble has been taken in condensing each entry as much as possible, it is important to note that the work is in no sense simply a compilation of definitions of chemical terms. It gives brief accounts of substances, operations, apparatus, plant and so on, and may be fairly described as a handbook in which ease of reference is achieved by arranging the articles in alphabetical order.

J. M. ROBERTSON.

Thompson, Lilian Gilchrist. "*Sidney Gilchrist Thomas. An Invention and its Consequences.*" 8vo. Pp. 328, illustrated. London, 1940 : Faber and Faber, Ltd. (Price 12*s.* 6*d.*)

This is the story of a young Englishman and the part he played in the development of the World's iron resources. It is admirably written by his sister, and although based mainly on " Memoir and Letters of Sidney Gilchrist Thomas " edited by his cousin R. W. Burnie in 1891, new material, including a chapter on the present use of the basic process and the economic results of Thomas' invention, has been added.

The commercial application of the Bessemer process was, on its introduction, limited to non-phosphoric ores, so that it was not surprising that the ever-perplexing problem of dephosphorisation took first place in the minds of the iron and steel manufacturers. Throughout the pages of the early volumes of the *Journal of the Iron and Steel Institute* can be traced the efforts of those workers, including Lowthian Bell, Snelus, Riley and others, to arrive at a satisfactory solution of this problem, yet it remained to one without previous training or financial backing and whose profession was that of a London Police Court Clerk to devise, with the assistance of Percy C. Gilchrist, means for the successful dephosphorisation of iron, and so make available those vast deposits of ore hitherto useless for the manufacture of iron and steel.

The announcement of the discovery of the basic process was first made public in a paper entitled " On the Elimination of Phosphorus " by Sidney G. Thomas and Percy C. Gilchrist which was presented to the Iron and Steel Institute in 1879. Its commercial adoption was rendered possible by the co-operation of E. P. Martin, Edward Windsor Richards and Edward Riley. The basic process adaptable to both the Bessemer and open-hearth processes revolutionised the whole of the steel output of the world, and enabled Germany alone to double its output of steel in a single decade.

The value and importance of the highly phosphoric slag produced in the process soon attracted the attention of Thomas, and experiments were carried out, the results of which confirmed his opinion of the manurial value of the product in agriculture, and led to its universal use as a fertiliser.

Sidney Gilchrist Thomas died in 1885, at the age of thirty-five, recognised throughout the steel-producing countries as one of the greatest contributors to the advancement of steel manufacture.

The story of this young man, burdened by ill-health and with many handicaps to overcome, should prove a source of inspiration to those whose business career is before them. No person engaged in the manufacture of iron and steel, whether executive or employee, should miss reading this absorbing volume.

To this memoir of her brother, Mrs. Thompson has added some account of her stewardship of the money left by Thomas for charitable and social work.

R. E.

REFRACTORY MATERIALS

Trends in Refractories for the Basic Open-Hearth Furnace. R. P. Heuer. (Metals and Alloys, 1940, vol. 11, Apr., pp. 95–98; May, pp. 152–155). The author discusses the use of specially prepared magnesite and chrome bricks instead of silica bricks for the roofs of basic open-hearth furnaces. The bricks were made with mixtures of coarse and fine particles using presses capable of exerting a pressure of 10,000 lb. per sq. in. After trials, the author considers that the longer life obtained is sufficient to offset the higher initial cost. In the second part of his paper the author discusses methods of suspending chrome-magnesite bricks to form the roof of an open-hearth furnace, and describes a design of a roof in which steel sheet $\frac{1}{32}$ in. thick is inserted in all the joints; in service the steel oxidises and expands and the oxide combines with the refractory material to form a tight monolithic mass; expansion joints $\frac{3}{4}$ in. wide are provided every 3 ft. in both directions. In conclusion he states that, whilst the cost of rebuilding such a roof may be five times as much as that of a silica-brick roof, not only is the life of the former much longer, but such items as reduced time for repairs, increased rate of melting and reduction in fuel costs must also be taken into account. Sufficient data on the use of basic roofs for open-hearth furnaces are not yet available and much development work remains to be done.

Up-to-Date Insulation of Hot-Blast Stoves. E. H. Younglove. (Blast Furnace and Steel Plant, 1940, vol. 28, May, pp. 461–463). The author discusses the development of insulating linings for hot-blast stoves. From a study of the average temperatures throughout a complete cycle in the operation of a hot-blast stove it has been found that the ideal design of a lining of efficient insulating blocks (made of diatomaceous silica bonded with asbestos fibre) would consist of a wall for the checker area tapering from $8\frac{1}{2}$ in. thick at the top to 1 in. at the bottom, and for the combustion area a wall about $7\frac{1}{2}$ in. thick throughout. There are, however, constructional difficulties which prevent this ideal design from being constructed. In new stoves the design is approximately realised by constructing the steel shell with a decrease in diameter from top to bottom. Existing stoves can be relined economically by making a composite wall with a total thickness of $15\frac{1}{2}$ in., which varies from 9 in. of firebrick and $6\frac{1}{2}$ in. of insulating brick at the top to $13\frac{1}{2}$ in. of firebrick and 2 in. of insulating brick at the bottom. The author also recommends that more attention be paid to the efficient insulation of hot-blast mains and bustle pipes.

FUEL

Studies in the Constitution of Low-Hydrogen Coals from the Collie Field of Western Australia. C. R. Kent. (Fuel in Science and Practice, 1940, vol. 19, June, pp. 119–125). An account is given of investigations of the petrographical characteristics, composition, extraction products and yields of acids and esters, isolated after fractionation, of samples of coal from the Collie Field of Western Australia. The properties of these coals which show their most marked differences from what may be termed " normal coals " may be satisfactorily attributed to their low hydrogen contents.

Some Problems Related to the Preparation of Illinois Coals. L. C. McCabe. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, Jan., pp. 1–4). The author discusses methods of separating the coal from the stone and refuse in the preparation of Illinois coal for sale.

The Effect of Preparation on Ash Fusibility as Revealed by a Study of Selected Illinois Coals. L. C. McCabe and O. W. Rees. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, Nov., pp. 693–698). The authors discuss the effect of screening, and of separation by methods based on differences in specific gravity, on the softening temperature of the ash from ten representative coals mined in Illinois.

Coal-Cleaning Plant at Allerdale Coal Co., Ltd. (Colliery Guardian, 1940, vol. 161, July 26, pp. 79–81). A description is given, with diagrams and illustrations, of the reconstructed coal-washing plant at the William pit of the Allerdale Coal Co., Ltd., in Cumberland, which treats about 50 tons of raw coal per hr.

Effect of Coal Characteristics on Pulverized Coal Firing. O. Craig. (Mechanical Engineering, 1940, vol. 62, June, pp. 452–454). The author discusses how the efficiency of pulverised coal as a boiler fuel is affected by the amount of volatile matter, the ash content, the amount of air required for combustion, the agglutinating properties and the moisture and sulphur contents of the coal.

Mechanical Equipment of Coke-Oven Batteries. H. C. Wood. (Iron and Coal Trades Review, 1940, vol. 141, July 26, pp. 89–90). The author reviews the progress which has been made in the last twenty-five years in the design of mechanical equipment for coke-oven batteries. He describes and illustrates coal-charging cars, coke pushers and door extractors, and tilting coke-quenching cars.

The Selection of Coals for Carbonisation. (Coke and Smokeless-Fuel Age, 1940, vol. 2, May, pp. 100–103, 112). In this article Mott

and Spooner's method of assessing the properties, in particular the coking properties, of coal is reviewed. Their method is a modification of the American Society for Testing Materials classification. Mott and Spooner judge the properties of the coal by its position in the coal band using data relative to the volatile matter and calorific value. From these data the carbon and hydrogen contents, the British Standard swelling number and the thermal yield of gas are calculated. The chief value of their work lies in the demonstration of the inter-relationships between the different properties of coal.

Plastic Properties of Bituminous Coking Coals—Effect of Petrographic Composition. R. E. Brewer, C. R. Holmes and J. D. Davis. (Industrial and Engineering Chemistry, Industrial Edition, 1940, vol. 32, June, pp. 792–797). The authors report on their investigation of the relation between the petrographic composition and the plastic properties of six representative American bituminous coking coals.

The New Light Oil Refining Plant of the Wheeling Steel Corporation. E. Preston and B. J. C. Van der Hoeven. (Blast Furnace and Steel Plant, 1940, vol. 28, May, pp. 455–460). The authors present an illustrated description of the semi-continuous light-oil refining plant built in 1939 for the Wheeling Steel Corporation at Follansbee, West Virginia. This plant refines the crude light-oil from the coke-ovens. It has been found advantageous, in order to be in a position to meet changing market conditions, to design the plant for the removal of " fore-runnings " and the production of motor fuel by continuous fractionation, and for the separation of pure benzol, toluol and xylol into their various marketable products by batch distillation. The plant comprises two continuous rectifying columns and one batch still with their accessories. The sequence of processes is described, and a flow diagram and operating data are presented.

Some Reflections on Coke-Screening Plant. (Coke and Smokeless-Fuel Age, 1940, vol. 2, June, pp. 135–137). In this discussion of the theory and practice of coke-screening it is suggested that it would be beneficial to the coke industry to set up screening stations at large distributing centres, so that the coke is screened as near to the consumer as possible. As a result of much research into screening, certain basic principles have been established, and the efficiency of screening has been found to be governed by the following considerations : (1) For a given screen and a given opening, the mean dimension of the largest screenable piece can only be determined by experience ; (2) the efficiency of screening is constant for a constant quantity of screenable pieces ; and (3) for a given capacity, the efficiency of screening is sensibly inversely proportional to the quantity of screenable pieces. Rouveix's calculations, by which he establishes a relationship between the dimensions of coke particles which will fall through a screen, the size of the openings in

the screen and the velocity of the coke approaching the screen, are reproduced.

New Method of Evaluating the Physico-Mechanical Properties of Coke. N. S. Gryaznov and T. G. Zyryanova. (Koks i Khimiya, 1939, No. 10–11, pp. 9–13). (In Russian). The authors discuss how the quality of coke affects the working of a blast-furnace. They are of the opinion that the following factors are of primary importance : (1) The extent to which the screen analysis of the coke is changed after subjecting it to a drum test ; (2) the degree of uniformity in the lump size after the drum test ; and (3) the degree of fissuring after subjecting the sample to a twelvefold dropping testing. The third factor was found to be independent of the degree of fissuring before testing. The authors derived coefficients characterising the first two factors by evaluating the drum test results.

Coke Quality and the Working of the Blast-Furnace. A. S. Bruk. (Koks i Khimiya, 1939, No. 10–11, pp. 7–9). (In Russian). A brief review of the influence of the quality of the coke on blast-furnace operation is presented and reference is made to some relevant Russian investigations. The deleterious effect of the ash content of the coke has been established, and means to reduce the ash should be sought. The chemical activity of coke, though of undoubted import, remains as yet objectively undefined. The degree of fissuring, the resistance to crushing, and the lump size and uniformity are also considered in connection with their relation to the behaviour of the coke in the blast-furnace.

Hydrogenation of High-Volatile Bituminous Coals. L. L. Hirst, H. H. Storch, C. H. Fisher and G. C. Sprunk. Industrial and Engineering Chemistry, Industrial Edition, 1940, vol. 32, June, pp. 864–870). The authors present and discuss the results obtained by the hydrogenation on a laboratory scale of three bituminous, high-volatile American coals.

PRODUCTION OF IRON

Welded Blast-Furnace Stack. L. J. Gould. (Iron and Steel Engineer, 1940, vol. 17, June, pp. 23–27). The author describes the design and erection of new mantle plating to one of the blast-furnaces at the Maryland Works of the Bethlehem Steel Co. The furnace was 74 ft. high, 23 ft. in dia. at the bosh and 17 ft. in dia. at the top. It was desired to preserve the former interior lines of the furnace. By employing electric welding and a carefully planned method of erection, a new mantle was built up on the outside of the old one, and the old one was removed without dismantling the dome and bell at the top.

Reminiscences of the First Application of Dry Blast. L. E. Riddle. (Eastern States Blast Furnace and Coke Oven Association : Blast Furnace and Steel Plant, 1940, vol. 28, May, pp. 464–470). The author gives an account of Gayley's work in developing the drying of the blast for blast-furnaces, and of its successful application at the Isabella furnaces, Pittsburgh, in 1904.

Utilising Waste Material in the Iron and Steel Industry. E. A. Wraight. (Mining Journal, 1940, vol. 209, Apr. 27, pp. 266–267). The author briefly reviews the manner in which by-products, flue dust, slag, mill scale, scrap metals and used refractory bricks at coke-ovens, blast-furnaces and steel plants may be utilised to advantage.

The Growth of the Soviet Steel Industry. (Iron and Steel, 1940, vol. 13, July, pp. 392–396). An account is given of the great developments which have taken place in the iron and steel industry of the U.S.S.R. during recent years. During the first Five-Year Plan 17 blast-furnaces and 45 open-hearth furnaces were built. In accordance with the second Five-Year Plan 20 blast-furnaces, 86 open-hearth furnaces and 49 rolling mills were erected. The third Five-Year Plan (commenced in 1938) makes provision for still further developments, including the production of special steels. A map shows the positions of the mines and new works and some particulars are given of the individual concerns.

Old Stone Furnace. E. S. Dawson and M. H. Mawhinney. (Steel, 1940, vol. 107, July 8, pp. 62–65). The authors describe an old stone blast-furnace called the Rebecca Stack, which was built at Lisbon, Ohio, in 1807. The furnace was about 30 ft. high, and produced 2 tons of iron per day using charcoal and local ores.

FOUNDRY PRACTICE

Produces Variety of Steel Castings. D. F. Seyferth. (Foundry, 1940, vol 68, June, pp. 44–45, 129). The author gives a brief illustrated description of the plant of the West Michigan Steel Foundry Co., Muskegon, which produces about 500 tons of small steel castings per month. A high degree of mechanisation has been achieved, and attention is paid to inspection of the castings at an early stage in the finishing operations, so as to avoid doing work on a casting which might have to be rejected.

Steel Valve Castings. J. J. Kanter. (Iron Age, 1940, vol. 146, July 11, pp. 29–33). The author describes developments in the technique of steelmaking and casting which permit of the manufacture of small steel castings free from porosity, such as steam valves for use at high pressures and temperatures up to 1000° F. Particular reference is made to the use of H.F. induction furnaces.

Cast Steel Parts for the Ford Tractor. R. H. McCarroll and E. C. Jeter. (Metal Progress, 1940, vol. 37, May, pp. 521–526). The authors describe the moulding and casting equipment and technique employed at the Dearborn Works of the Ford Motor Co. for the manufacture of steel castings for the Ford tractor. The main purpose of this new equipment is to cast continuously instead of intermittently, and this is achieved by utilising electric holding furnaces for the metal and conveyor reels for bringing the moulds direct to the pouring spouts. One melting and casting unit is capable of producing 80 tons of front axles, radius rods, steering sectors and wheel flanges in 16 hr. The authors also give the analyses, heat treatment and physical properties of the steel used for various parts and present numerous illustrations of the foundry equipment and finished castings.

Advanced Foundry Technique Used to Cast 10-Ton Stainless Steel Plaque. (Industrial Heating, 1940, vol. 7, May, pp. 395–398). A brief illustrated description is given of the methods of moulding, casting, machining and finishing employed in the manufacture of a stainless-steel panel with figures in relief symbolising " News." The panel is approximately 17 ft. × 22 ft. in size and weighs 10 tons.

Cooling and Storage of Foundry Sand. H. L. McKinnon. (American Foundrymen's Association : Foundry Trade Journal, 1940, vol. 63, July 11, pp. 21–23). The author presents data relating to the necessity for and means of cooling moulding sand in foundries where a high rate of production is required and where a large propor-

tion of the sand is reconditioned for further use. When the ratio of the volume of metal to that of the sand in the moulding box is high, the sand becomes very hot, and the author illustrates this by graphs showing the temperature of the sand and the amounts of air and water required for cooling 100 lb. of sand for various metal/sand ratios under given conditions of casting. In conclusion he discusses the design of suitable bins for the storage of dry and moist moulding sands, with particular reference to the slope of the sides and the size of the opening at the bottom.

A Comparative Study of Some British Coal Dusts in Green-Sand Mixtures. A. N. Sumner. (Foundry Trade Journal, 1940, vol. 63, July 18, pp. 41–42). With a view to discovering the most suitable coal dust for mixing with green sand in order to improve the surface finish of certain castings, the author made a series of tests by casting bars 36 in. × 6 in. × 2 in., using mixtures of floor sand and green sand with coal dusts from different English coals. After tests with thirty samples of coal dust and blacking, he found that an addition of 8–10% by volume of Staffordshire fine-grade coal dust produced the best results.

Eliminate Variables in Core Testing. H. S. Austin and C. E. Schubert. (Foundry, 1940, vol. 68, June, pp. 42–43, 122–123). The authors suggest a standard specification for the procedure for testing core-binding oils which would make it possible for the suppliers to offer oils on a competitive basis to fulfil the requirements of the foundry.

PRODUCTION OF STEEL

Crucible Steel Made in America. (Metal Progress, 1940, vol. 37, May, pp. 527–532). An illustrated description is given of the equipment and processes at the only remaining works in America where crucible steel is made. These are the works of the Crucible Steel Co. of America at Pittsburgh. The crucible melting shop contains one furnace with six openings on the floor level ; it is fired by natural gas and heats thirty crucibles, each containing a charge of 100 lb. The charges are melted in about 3 hr. and held for a further 45 min. before teeming.

Producing Steel to Meet Physical Test Requirements. C. H. Herty, jun. (American Iron and Steel Institute, May, 1940, Preprint). The author discusses the difficulties that a steelmaker has to contend with in the production of steel to comply with stringent specifications. He deals mainly with steels for plates, bars, wire and strip, and states that technical committees of the American Iron and Steel Institute are endeavouring to formulate definitions, classifications and rational standards for products which will meet the need of both supplier and consumer.

Copperweld Goes Alloy. T. C. Campbell. (Iron Age, 1940, vol. 145, June 13, pp. 30–32). The author describes the melting and pouring practice at the works of the Copperweld Steel Co., Warren, Ohio, where various alloy steels and the steel for manufacturing copper-covered wire and rods are made. At these works there are two 25-ton Swindell-Dressler 12,000-kVA. electric furnaces and one 6-ton Héroult electric furnace. The equipment for stripping the ingots consists of two ingot-mould tilting machines, one 100-ton stripper and an ingot-mould car all controlled from a pulpit by one operator.

Copperweld's New Alloy Steel Plant. J. D. Knox. (Steel, 1940, vol. 106, June 3, pp. 91–116). The author presents a detailed and fully illustrated description of the general layout and individual units at the works of the Copperweld Steel Co., Warren, Ohio, where electric furnaces are used for the production of aircraft-quality steel, high-alloy and tool steels, and S.A.E. steels.

New Alloy Plant for Copperweld Steel Company. (Iron and Steel Engineer, 1940, vol. 17, June, pp. 68–69). A brief illustrated description is given of the recently erected plant of the Copperweld Steel Co., Warren, Ohio. (*See* preceding abstracts).

Sulphur Control in the Basic Open Hearth. H. J. Sweeney. (Blast Furnace and Steel Plant, 1940, vol. 28, Apr., pp. 391–394,

397, 398). In discussing means of removing sulphur when producing steel by the basic open-hearth process, the author points out that when sulphur-bearing scrap has to be used it should be charged last, as this will facilitate the removal of the sulphur. He states also that for economic reasons it is often advisable to charge all the sulphur-bearing scrap into one heat and spend the time necessary for removing the sulphur on this one heat rather than to distribute this scrap over eight or ten heats. He presents some data relating to the effect of sulphur in the coal used in the gas producer on the sulphur content of the steel before the slag action begins. In conclusion he mentions some experiments in which the alumina content of the slag was purposely raised to $12–14\%$; this caused the slag to absorb the sulphur from the melt very rapidly; this subject, however, requires further investigation.

Slag Control. C. H. Herty, jun. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1182 : Metals Technology, 1940, vol. 7, June). The author enumerates the following five objects in the operation of slag control in the open-hearth furnace : (1) To produce a slag in the furnace that will eliminate phosphorus and sulphur to the desired extent without excessive use of lime or excessive loss of iron as oxide; (2) to conserve both lime and deoxidisers; (3) to prevent excessive waste of iron in the slag; (4) to shorten the melting period by using as little limestone as possible; and (5) to standardise the conditions of oxidation so that the deoxidising additions will unfailingly produce the desired type of ingot. He discusses next the lime/silica ratio necessary in slag to produce a specified low-sulphur content in the steel and how this ratio is affected by the amount of silicon in the hot metal. He then considers how the character of the slag can be estimated by analysis, colour, nature of surface and viscosity, and in conclusion gives some examples of the slag-control technique for producing specified types of steel.

Coreless Induction Furnace Developments. O. Dörrenberg and W. Bottenberg. (Foundry Trade Journal, 1940, vol. 63, July 18, pp. 37–38). An abridged English translation is presented of an article describing the development in Germany during the last ten years of coreless induction furnaces for steelmaking. The original article appeared in Stahl und Eisen, 1940, vol. 60, Feb. 8, pp. 116–119. (*See* Journ. I. and S.I., 1940, No. I., p. 235 A).

Tailor-Made Steels. T. Grey-Davies. (Sheet Metal Industries, 1940, vol. 14, June, pp. 605–607). Continuation of a series of articles (*see* p. 120 A). In Part XV. of this series the author considers some defects in finished steel sheets and traces the cause to defects in the original ingot. He refers to the " shadow " which can sometimes be observed on an ingot immediately after stripping. This shadow indicates the existence of blow-holes near the surface, for these cause a more rapid cooling of the skin at that particular area. Such an ingot, the author suggests, should be very carefully reheated

in order to avoid any undue oxidation of the surface, which would cause trouble in the subsequent rolling processes. He also discusses possible causes of the sticking of sheets during the rolling and annealing of packs.

The Manufacture of Steel by the Perrin Process. B. Yaneske. (Iron and Steel Institute, 1940, this Journal, Section I.). A new steelmaking process that can be operated on a large commercial scale is described, in which molten pig iron containing about 0.30% of phosphorus is blown in an acid-lined Bessemer converter, and the resultant blown metal is rapidly dephosphorised by pouring it from a sufficient height into a basic oxidising slag contained in the casting ladle. Ferro-alloys are then added in a red-hot condition to the dephosphorised blown metal and the finished steel is cast into ingots. By this method low-carbon-steel ingots can be manufactured direct from the acid Bessemer converter when using a pig iron that is too high in phosphorus for the normal acid Bessemer process.

The slag employed for the dephosphorisation of the Bessemer blown metal may either be a synthetic slag, or a basic open-hearth furnace slag sufficiently low in acids and high in iron oxide, such as may be obtained in the making of a low-carbon rimming steel heat. Examples are given, however, showing that the dephosphorisation is not so intensive with a basic open-hearth slag as with the synthetic slag, owing to the much lower acid content of the latter. It is also shown that the intensity of the dephosphorisation can be regulated to a certain extent by the percentage of dephosphorising slag employed.

For the production of acid open-hearth steel from the same phosphorus-bearing pig iron, a duplex process is employed in which the dephosphorised partly-blown metal containing a sufficient percentage of carbon is charged into an acid open-hearth furnace and the heat finished under an acid slag to the required chemical composition.

REHEATING FURNACES

Heating of Steel. P. J. McKimm. (Steel, 1940, vol. 106, June 17, pp. 54–61, 75 ; June 24, pp. 50–59 ; vol. 107, July 1, pp. 52–56, 68). The author describes and illustrates some of the defects in rolled steel which are caused by incorrect temperature or uneven heating in the soaking pit. In considering whether an ingot is carburised or decarburised in the soaking pit, the author states that in his experience with a variety of fuels and heating conditions neither of these effects is produced. He describes a number of tests the results of which confirm this view. He also describes a test which showed that a low-carbon steel ingot can be heated until 2 in. of the surface metal has been melted away without any deleterious effect on the surface remaining, or on the quality of the slabs rolled from it.

Observations on the Heating of Steel from the Metallurgical Standpoint. E. E. Callinan and G. Soler. (Iron and Steel Engineer, 1940, vol. 17, June, pp. 48–54). The authors describe the effects of changes in soaking-pit practice on the surface quality of rolled blooms of the following types of steel : Plain carbon, nickel, nickel-molybdenum, chromium, nickel-chromium, manganese, chromium-molybdenum, chromium-vanadium, chromium-nickel-molybdenum and 18/8 stainless. They consider first how the thermal conductivity of steel varies with the amount of alloying elements present, and the effect of this on the time required for soaking. They present several series of graphs in which the following factors are plotted in relation to the tons of steel hand-chipped per man per hour : (a) The track time, which is the time from the teeming of the last ingot mould to the completion of charging the soaking pit ; (b) the pit time, which is the period following that defined in (a) until the first ingot is removed from the pit ; (c) the stabilising time, which, in the furnace under discussion, is the period from the moment when the fuel rate drops below 2000 cu. ft. of natural gas per hr. ; and (d) the furnace temperature at the time the first ingot is taken out. They also describe and illustrate several types of surface defects found in alloy steels due to incorrect soaking-pit practice.

Automatic Combustion Control in the Steel Mill. M. J. Boho. (Blast Furnace and Steel Plant, 1940, vol. 28, Apr., pp. 395–397). The author describes some of the difficulties overcome in the development of automatic fuel control in the heating of soaking pits and some of the attempts which are now being made to apply automatic control to open-hearth furnaces.

The Action of Sulphur in the Fuel on the Steel Heated in the Furnaces. V. Kopytov and P. Sorokin. (Stal, 1939, No. 9, pp. 47–50). (In Russian). Results of previous investigators on the effect on steel of hot gases containing sulphur dioxide or hydrogen sulphide are reviewed. The authors' own experiments were carried out on low- and high-carbon steel and on a chromium-nickel steel (chromium $1 \cdot 16\%$ and nickel $3 \cdot 22\%$) in the form of cylindrical specimens which were heated in a tubular furnace fired by a mixture of town gas, air and sulphur dioxide. The proportion of town gas to air was such as to ensure complete combustion. The presence of SO_2 was found to accelerate scaling. The chromium-nickel steel was generally less stable than the carbon steels with greater penetration of sulphides into the interior at lower temperatures.

Steel Plant Furnaces—Section 4. Furnaces for Sheets and Strips : Part I. M. H. Mawhinney. (Industrial Heating, 1940, vol. 7, Jan., pp. 42–46). Continuation of a series of articles (see Journ. I. and S.I., 1940, No. I., p. 186 A). The author describes a modern batch furnace for reheating billets and slabs for rolling into plates.

New Equipment at the Newcastle Steel Works. Reheating Furnace at the Plate and Bar Mill. W. H. Brooke. (Broken Hill Proprietary Review, 1940, vol. 17, Apr., pp. 4–6). The author describes and illustrates a new reheating furnace recently installed at the Newcastle Works (New South Wales) of the Broken Hill Proprietary Co., Ltd. The furnace has a capacity of 45 tons of slabs per hr. and the fuel used is a mixture of blast-furnace and coke-oven gas and air preheated in a Schack recuperator. The furnace is arranged in two main zones, viz., the heating zone and the soaking zone ; the former has two sections, the convection or preheating portion, and the main heating portion. A very complete system of temperature recording and fuel control has been incorporated.

FORGING, STAMPING AND DRAWING

The Rôle of Production Forgings in Industry. W. Naujoks. (Industrial Heating, 1940, vol. 7, Mar., pp. 216–221; Apr., pp. 304–306). The author describes and discusses numerous applications of light and heavy forgings for production machinery, aircraft and ships as well as for tools and sports goods.

Forgings for Aircraft. J. Allison. (Steel, 1940, vol. 107, July 8, pp. 49–50). A brief account is given of the precautions taken to ensure the good quality of the small forgings for aircraft produced at the works of Billings and Spencer Co., Hartford, Connecticut.

Hammers, Hatchets, Sledges, Et Cetera. C. C. Hermann. (Iron Age, 1940, vol. 146, July 11, pp. 38–41). The author describes the sequence of processes in a forging shop producing hammers, axes and other tools.

Dies of Cast Iron. R. Bredenbeck. (Iron Age, 1940, vol. 145, May 16, pp. 38–39). The author discusses the advantages of using some of the high-tensile cast irons which are now available for the manufacture of dies for pressing machinery.

Valve Production by the Extrusion Process. (Engineer, 1940, vol. 159, May 31, p. 494). **The Extrusion Process of Valve Production.** (Machinery, 1940, vol. 56, July 4, pp. 438–440). An illustrated description is given of the extrusion process of making valves for internal combustion engines. With this process it is possible to manufacture several thousand valves per shift, using the special steel required for making aero-engine exhaust valves.

Deep Drawing of Mild Steel. P. Mabb. (Metal Treatment, 1940, vol. 6, Summer Issue, pp. 72–78). In this discussion of some of the general features of the deep-drawing of mild steel, the author deals with the effects of hot-working, cold-working, annealing and composition on the deep-drawing properties. In conclusion he considers the essential properties of lubricants and of the steels for punches and dies for pressing operations.

The Saving in Power Achieved by Reactive Drawing. H. A. Stringfellow. (Wire and Wire Products, 1940, vol. 15, May, pp. 256–259). The author briefly describes a back-pull wire-drawing machine equipped with die pressure-indicating devices, speed-controlling mechanisms and means of varying the ratio of the back pull to the forward pull. With this machine it was possible to make comparative determinations of the relative power consumed by back-pull and conventional drawing, on the same machine, through the same die, with the same lubricant on the

same wire, and with the ability to vary the speed of drawing and the pull ratio within extreme limits. The author has reduced the power-consumption units to kilowatt-minutes per foot of wire. The average of twenty-four determinations when drawing 0·63% carbon steel wire showed that conventional drawing required 0·0074 of the above units and back-pull drawing only 0·0068 units. Calculations made from the readings obtained show that : (1) When drawing with a pull ratio of 50%, the saving in power is 12·15%, but if the pull ratio is 31% the saving is only 5·40% ; and (2) with the same pull ratio there is a greater saving of power with a light reduction in diameter than with a heavy reduction, *e.g.*, using a 50% pull ratio the saving in power with a 24% reduction was 5·90%, whilst with an 8% reduction the saving was 10·8%. The author presents tables of the results obtained and explains the calculations which led him to the above conclusions.

Reactive Drawing Results. K. B. Lewis. (Wire and Wire Products, 1940, vol. 15, May, pp. 260, 261, 281, 282). In a critical examination of the data presented by Stringfellow relating to the saving in power by applying " back-pull " in wire-drawing processes (*see* preceding abstract), the author considers the die friction ; this depends on the yield point of the wire, the area of contact and the coefficient of friction. He points out that the friction acts only in the die and if the wire enters this stressed to half its yield point by the back-pull, the friction will be reduced by one half ; he then calculates the total friction and the amount of friction which should have been saved by a given back-pull and compares this with the amount actually saved as determined by Stringfellow. The figures are not in good agreement and the author discusses some possible explanations of this.

Improvements in Wire and Rod Baking Practice. J. M. Petix. (Wire and Wire Products, 1940, vol. 15, June, pp. 309–311). The author describes one of the modern types of baking ovens for wire. In this type the oven is indirectly heated by a forced circulation of air passing over an oil- or gas-fired heating unit. The oven is constructed of a number of insulated panels of uniform width with tongued-and-grooved joints, and the wire is passed through the baking space either on small trucks running in steel channels or suspended on hooks moving along an overhead rail.

ROLLING-MILL PRACTICE

Modern Lubrication of Existing Equipment. F. J. Thomas. (Iron and Steel Engineer, 1940, vol. 17, June, pp. 39–45). The author describes, with numerous practical examples, methods of improving lubrication systems in rolling mills.

Dimensional Variations in Hot-Rolled Steel Mill Products and the Problem of Control. A. C. Cummins. (American Iron and Steel Institute, May, 1940, Preprint). The author reviews the history of the introduction of tolerances and rolling margins in American specifications for steel plates, bars and sections, and discusses the methods of control which are necessary to ensure that rolled steel will comply with these specifications.

Electrical Equipment for the Edgar Thompson Slabbing Mill. R. H. Wright and B. J. Auburn. (Iron and Steel Engineer, 1940, vol. 17, June, pp. 30–36). The authors describe the electric motors, auxiliaries and switching system of the electrically driven slabbing mill at the Edgar Thompson Works of the Carnegie-Illinois Steel Corporation. The vertical rolls at this mill are 36 in. in dia. and they are driven by a 3000-h.p. motor through a combination bevel and reduction gear unit. The horizontal rolls are driven by two 5000-h.p. reversing motors, each roll being directly connected to one motor.

Slivers in Cold Reduced Strip. P. J. McKimm. (Blast Furnace and Steel Plant, 1940, vol. 28, Apr., pp. 338–340). Conclusion of a two-part article (*see* p. 58 A). In discussing how scale on hot strip can cause defects known as " slivers " in subsequent cold-rolling, the author stresses the necessity of soaking the strip at the correct temperature so as to produce a uniform scale which is readily removed at the scale-breaker and the first spray. Other possible causes of these defects are the rubbing of the strip on the apron plates of the hot-mill run-out table, and the tightening of one winding of a coil on the winding below it, thus causing scale to be dragged and embedded in the surface of the strip.

Rolling With the Help of Idle Edgers. N. A. Sobolevsky. (Blast Furnace and Steel Plant, 1940, vol. 28, Apr., pp. 333–337). The author states that, in the process of rolling, the rolls build up a pulling force much greater than that necessary to keep the process going. He presents a series of calculations by which this force can be determined, and suggests that the force should be applied to push the metal between suitably placed idle vertical rolls in order to obtain further reductions in section. He describes some

experiments carried out with a strip mill at the Magnitogorsk Works (in the U.S.S.R.) which demonstrated the advantages of the application of such a process.

Bethlehem Installs New Continuous Pipe Mill. L. J. Hess. (Iron Age, 1940, vol. 145, June 13, pp. 38–39). **Installs New Continuous Pipe Mill.** L. J. Hess. (Steel, 1940, vol. 106, June 24, pp. 47–48, 78). The author presents a brief illustrated description of a continuous tube mill recently put in commission at the Maryland works of the Bethlehem Steel Co. The mill, which operates on the Fretz-Moon principle, has a capacity of 16 tons per hr. of tube from $\frac{3}{8}$ in. to 3 in. in dia. The skelp is supplied in coils of 35 and 48 in. dia., instead of in flat lengths. The heating furnace is 147 ft. long and is equipped with 274 burners 9 in. apart with individual adjustment of the air-gas mixture. The mill is also equipped with a flash welder for butt-welding the ends of the coils before the strip enters the furnace, and a flying hot saw for cutting the tubes into the exact lengths required.

Direct-Coupled Motors for Steel-Mill Rollers. (Engineering, 1940, vol. 149, May 3, pp. 458–459). **Direct-Coupled Roller Motors.** (Metallurgia, 1940, vol. 21, Apr., pp. 195–196). A brief survey is given of the advantages of using individual motors for driving each roller in the roller table of a steel mill, and the design of a low-frequency motor and a variable-frequency converter for this type of drive is described and illustrated.

PYROMETRY

A New Two-Color Optical Pyrometer. H. W. Russell, C. F. Lucks and L. G. Turnbull. (Journal of the Optical Society of America, 1940, vol. 30, June, pp. 248–250). After stating that the monochromatic optical pyrometer fails if either the emissivity of the source or the transmission of the intervening space is unknown or variable, the authors derive an equation which indicates that if the ratio of the intensities of two radiations of different wavelengths is directly determined it will provide a direct measure of the temperature. They then describe and illustrate a two-colour optical pyrometer which applies this principle. The instrument contains an inclined semi-transparent gold mirror. The light from the objective lens strikes this, and the transmitted green light passes on to one photo-electric cell while the reflected red light passes to a second photo-electric cell. Suitable amplifier and potentiometer circuits enable the ratio of the different light intensities to be determined. The instrument described is suitable for determining temperatures over 1000° C.

Stability of Base-Metal Thermocouples in Air from 800° to 2200° F. A. I. Dahl. (Journal of Research of the National Bureau of Standards, 1940, vol. 24, Feb., pp. 205–224). The author studied the changes in the e.m.f. of chromel-alumel and of iron-constantan thermocouples heated in an oxidising atmosphere at various temperatures for various periods of time. The temperatures ranged from 800° to 2200° F. in steps of 200° F. and the periods at these temperatures ranged from 10 to 1000 hr. The results obtained are presented in numerous tables and graphs. The author points out that long-time exposure of a chromel-alumel thermocouple to high temperatures causes the e.m.f. corresponding to a given temperature to increase, whilst the effect on an iron-constantan thermocouple is just the reverse.

The Use and Maintenance of Heat Treatment Instruments. J. F. Bennett. (Metals Treatment Society of Victoria : Australasian Engineer, 1940, vol. 40, June 7, pp. 19–21, 37–40). The author reviews the temperature measuring, recording and controlling instruments which are now available for use with heat-treatment furnaces. He commences with some definitions and then describes vapour-pressure thermometers, gas-filled and solid-filled thermometers, thermo-electric, optical and radiation pyrometers and expansion instruments. He concludes with some recommendations on the testing and calibration of pyrometers.

HEAT TREATMENT

Case Carburization of Steel. E. G. Mahin. (Iron Age, 1940, vol. 145, May 30, pp. 17–22 ; June 6, pp. 53–57). In the first part of his paper the author explains the theory and practice of pack carburising. He presents a curve of the equilibrium ratio of carbon monoxide and carbon dioxide at different temperatures in the presence of solid carbon and shows that the carburising temperature affects not only the surface hardness but also the case depth. He deals next with the action of energisers and the factors affecting the time for which the parts are kept at full carburising temperature. In the second part the author shows how the carbon content at different depths of case is affected as the steel passes the Ar_3 point on cooling. In conclusion he discusses the heat treatment of case-hardened steel and case-hardening by gases and salt baths.

Case Hardening in Liquid Baths. F. D. Waterfall. (Iron Age, 1940, vol. 145, June 27, pp. 27–31 ; vol. 146, July 4, pp. 32–35). The author describes case-hardening in salt baths as practised in England, pointing out how this differs from American procedure. He discusses the evidence for and against the statement that the cyanide case is too brittle and comes to the conclusion that it is less brittle than a case of similar depth produced by pack hardening. He presents data showing the effects of various factors (carburising time and temperature, bath composition, reheating temperature) on the depth and degree of hardening, core hardness and mechanical strength. He describes the response of three alloy steels to cyanide- and box-hardening and the cyanide-hardening of malleable iron ; the results achieved in mixtures of alkaline-earth chlorides and sodium cyanide are presented. Finally, he touches on the depth of copper-plating required to prevent the carburisation of the under-lying metal during different immersion periods.

The Use of Salt Baths. W. Nelson. (Metallurgia, 1940, vol. 22, June, pp. 55–57). The author discusses the advantages and limitations of salt baths for the hardening of steel with special reference to the factors governing the rate of penetration in cyanide baths.

Salt Baths for High Speed Steel Hardening. A. G. Robiette. (Machine Shop Magazine, 1940, vol. 1, Jan., pp. 76–79). The author gives a brief description of some electric salt-bath furnaces for the hardening of high-speed steel, for which temperatures up to 1350° C. are required.

Hardening in the Machine Shop. A. E. Shorter. (Machine Shop Magazine, 1940, vol. 1, Mar., pp. 80–83). The author describes a form of flame-hardening sometimes called " Shorterising." The

method can be carried out in four ways : (1) The burner, mounted on a machine head, is traversed along a defined path and is followed by a suitable quenching jet ; (2) the burner and quenching unit is stationary and is applied to the face of a slowly rotating cylindrical object ; (3) a stationary burner is applied to the face of a rapidly rotating object, which is thus raised to the critical temperature while leaving the core unaffected, and the quenching spray is then applied ; and (4) a combination of (1) and (3) is employed in which the burner and quenching unit traverse the rotating object.

Economy in Machine Replacements—Flame Hardening by the Shorter Process. (Iron and Steel, 1940, vol. 13, July, pp. 413–416). A brief outline of the development of the Shorter process of flame-hardening is given together with several examples of its application and a table setting out the analyses, mechanical properties and hardness of a number of carbon and low-alloy steels treated in this way.

Surface Hardening Machine. (Machine Shop Magazine, 1940, vol. 1, June, pp. 84–87). An illustrated description is given of a new flame-hardening machine intended for the treatment of spur, single and double helical bevel gears and all straight surfaces. The machine consists of a fabricated and machined steel carriage on four wheels moving on rails along the top of a tank. The carriage carries a head on which the adjustable blowpipe is mounted. The burner has a travel of 36 in. and gears up to 6 ft. in dia. can be accommodated. The tank forms the quenching unit and it is provided with suitable waterways, sprays, valves, water-level control and baffle plates.

The Nitriding Process of Case-Hardening. J. E. Hurst. (Machine Shop Magazine, 1940, vol. 1, May, pp. 84–87). The author describes the theory and practice of nitriding, a surface-hardening process very suitable for the vanadium-chromium-molybdenum and the chromium-nickel-molybdenum steels described in some of the Air Ministry specifications.

Nitriding Tool and Austenitic Steels. D. W. Rudorff. (Metallurgia, 1940, vol. 22, June, pp. 63–65). The author reviews reports of two recent investigations in the U.S.S.R. on the accelerated nitriding of tool steels and the nitriding of austenitic steels ; the first was by Lipchin and Glazyuk and the second by Kosolopov (*see* Journ. I. and S.I., 1940, No. I., pp. 89 A and 90 A).

A Large Furnace for Normalising Round Bars. (Metallurgia, 1940, vol. 22, June, pp. 45–46). An illustrated description is given of a modern furnace for the normalising of round bars $\frac{3}{4}$ in. to 4 in. in dia. and 12 ft. to 20 ft. long. The hearth of the furnace is 30 ft. × 22 ft. and the average height of the chamber is 18 in. It is designed to normalise 60 tons of bars in 24 hr. An interesting feature is the system of overhead heating with producer gas, which is conducted across the width of the furnace by means of an overhead gas main from the bottom of which the ports conduct the gas into the furnace chamber.

Improving the Durability of Large Industrial Gears. E. J. Wellauer. (Metal Progress, 1940, vol. 37, June, pp. 653–657, 696). The author discusses methods of heat-treating large gear wheels, with special reference to means of maintaining freedom from distortion.

New FWD Heat Treating Department. J. Sorenson. (Industrial Heating, 1940, vol. 7, May, pp. 408–412). The author describes and illustrates the heat-treatment furnaces and temperature-recording instruments recently installed by the FWD Auto Co., of Clintonville, Wisconsin, for the treatment of motor lorry parts. For temperatures under 1200° F. the horizontal recirculating type of furnace is used, whereas furnaces without forced circulation are used for higher temperatures.

Scale-Free Hardening in Batch-Type Electric Furnaces. F. W. Haywood. (Machine Shop Magazine, 1940, vol. 1, Feb., pp. 78–81). The author describes some small heat-treatment furnaces for hardening batches of tools, &c., in which a controlled atmosphere consisting of the products of combustion of town gas is used. The operation of the " certain curtain " of mixed gas when the furnace door is opened is described in detail.

Dimension Changes of Tool Steels During Quenching and Tempering. E. Ameen. (Transactions of the American Society for Metals, 1940, vol. 28, June, pp. 472–512). The author reports on an investigation of the changes in dimensions which occur in the hardening and tempering of tool steels. Five types of steel in the form of small round bars and rings as normally used for making dies, taps and cuttings tools were investigated. These consisted of : (1) An unalloyed carbon steel (carbon 1·00%) with a wide hardening range but a shallow depth of case ; (2) a steel similar to the first but with a narrower hardening range and a greater depth of case ; (3) a tungsten steel (tungsten 0·92%) suitable for twist drills ; (4) an oil-hardening tool steel with tungsten 0·64%, chromium 0·56% and vanadium 0·11% ; (5) an air-hardening steel containing carbon 1·64%, chromium 12%, nickel 0·13%, molybdenum 0·94% and vanadium 0·17%. A very soft pure iron was also tested for comparison purposes. It was found that the stresses causing changes in dimension were of two kinds, thermal stresses tending to increase the dimensions of the specimen and transformation stresses which tend to decrease them. Factors such as a high cooling velocity and decreased thermal conductivity increase the deformation caused by the thermal stresses, and factors which increase the elastic limit at elevated temperatures reduce this deformation. The transformation stresses are decreased where part of the microstructure is a constituent which does not transform, e.g., retained austenite or excess carbide.

WELDING AND CUTTING

Spotwelding Machine Settings and Their Effect on Weld Strength.
A. M. Unger. (Iron Age, 1940, vol. 145, June 20, pp. 27–31). In
the design of electric spot-welding machines there are four factors
governing the properties of the finished weld ; these are : (1) The
current strength ; (2) the mechanical pressure on the electrodes ;
(3) the time during which the current flows ; and (4) the size and
shape of the electrodes. In this paper the author describes the
mechanism employed for controlling the first three of these factors
and the advantages of dome-shaped over flat electrode tips. In
conclusion he discusses the results of tests of the shear strength of a
large number of spot welds on $\frac{1}{8}$-in. high-tensile steel plate in which
15-, 30- and 50-cycle A.C. was used and the mechanical pressure was
varied in the range 600–1600 lb. The results indicated that the use
of 50-cycle A.C., high mechanical pressure and a long duration of
contact produced welds with the greatest shear strength.

**Hydrogen Atmosphere High Frequency Induction Furnace Used
for Brazing Spiralled Strip Tubing.** (Industrial Heating, 1940, vol. 7,
May, pp. 416–417). Brief particulars are given of a method of
manufacturing steel tubing from $\frac{1}{8}$ in. to $\frac{5}{8}$ in. in outside dia. of
carbon steel or of alloy steel. The tube is made from a helical coil
of strip wound cold which is subsequently welded into a solid-
walled tube in an atmosphere of hydrogen in a H.F. induction
furnace.

Metallic Electrodes for Gray Cast-Iron Welding. F. W. Scott.
(Welding Journal, 1940, vol. 19, June, pp. 217-S–221-S). The
author compares some of the results achieved in the electric welding
of grey cast iron with steel electrodes, bare cast-iron electrodes and
cast-iron electrodes coated with carbon, ferro-silicon and a flux.
The last-named type produced a sound and machinable weld.

Low Temperature Welding of Cast Iron. H. Klopstock. (Journal
of the Junior Institution of Engineers, 1940, vol. 50, July, pp.
271–290). The author describes a new low-temperature technique
for the welding of cast iron. The new process is more in the nature
of soldering than of welding, for the parent metal is not melted, the
temperature being only about 850° C. A welding rod of an iron-
carbon alloy called " Gussolite " is used together with a special
fluxing paste. Among the many advantages claimed for the process
are the following : (1) The finished joint can be machined without
difficulty, as the deposited metal has a Brinell hardness of about 200 ;
(2) the deposited metal has approximately the same coefficient of

expansion as the parent metal over the temperature range employed ; (3) the process can be applied to castings which are to be enamelled without fear of the joint subsequently affecting the enamel ; (4) the appearance of the weld metal is the same as that of the parent metal ; (5) castings need only be preheated to about 350–400° C. and in many cases preheating of the whole casting is not required at all ; and (6) owing to the low temperature the same process can be applied to copper. In the latter part of the paper the author describes a number of repairs, both large and small, which have been successfully carried out by this process.

Gouging or Flame Machining. R. F. Flood. (International Acetylene Association : Canadian Metals and Metallurgical Industries, 1940, vol. 3, June, pp. 152–154, 170). The author describes the technique and some applications of gouging. For this process an oxy-acetylene torch delivering a large volume of oxygen at low velocity is used to cut a smooth, accurately defined groove in the surface of steel plate. The process has four main applications, which are : (1) The progressive gouging of the underside of electric-arc welds ; (2) the removal of defective weld metal and of temporary tack-welds ; (3) the preparation of plate edges for welding ; and (4) for repair and maintenance work.

Welding Metallurgy. Part VI. The Weld Melt (Pure Iron). O. H. Henry and G. E. Claussen. (Welding Journal, 1940, vol. 19, June, pp. 413–417). Continuation of a series of articles (*see* p. 124 A). The authors explain in simple terms the changes which occur during the heating and cooling of pure iron ; from this they proceed to construct and explain the iron-carbon and iron/iron-carbide equilibrium diagrams.

Welding Metallurgy. Part VII. Difficulties. O. H. Henry and G. E. Claussen. (Welding Journal, 1940, vol. 19, June, pp. 417–422). Continuation of a series of articles. In this part the authors explain the causes of difficulties encountered in welding practice, such as hot cracks, burning of the metal, blow-holes, slag inclusions and insufficient penetration.

The Fundamental Nature of Welding. III.—Effects of Various Alloying Elements, Fluxes and Slags in Arc-Welding Rods. D. E. Babcock and S. A. Braley. (Welding Journal, 1940, vol. 19, June, pp. 222-S–230-S). Continuation of a series of articles (*see* p. 107 A). The authors review the literature on the effects of alloying elements, different fluxes and different slags contained in, or produced by, welding electrodes on the properties of the finished weld. A bibliography of 59 references is appended.

PROPERTIES AND TESTS

The Tension Test. C. W. MacGregor. (American Society for Testing Materials, June, 1940, Preprint 51). The author reviews important work on the interpretation of tensile test results and discusses various definitions of stress and reduction of area and the relation of test data to true values of strain and reduction of area. He suggests two new definitions, namely, the true uniform strain and the true local necking strain. He also describes experiments which show that these definitions of ductility yield more information on the deformation characteristics of the material than do the percentage elongation on 2 in. and the ordinary reduction of area. Some experimental results are given in the form of curves which show the relative values of the various magnitudes of strain and reduction of area along the length of fractured specimens of various steels.

Tensile Strength and Composition of Hot-Rolled Plain Carbon Steels. C. F. Quest and T. F. Washburn. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1182 : Metals Technology, 1940, vol. 7, June). The authors develop an equation which expresses the tensile strength of a steel in terms of the carbon, phosphorus and manganese contents. The equation is based on data accumulated over a number of years by the Inland Steel Co., and it is claimed to be valid for a range of analysis which includes the medium-manganese and the silicon-bearing steels.

Stress-Strain Relations for Malleable Cast Iron in Tension with Special Attention to Yield Point Determination. R. D. Landon. (American Society for Testing Materials, June, 1940, Preprint 37). The author reports on the results of tensile tests on 141 specimens of malleable cast iron representing a wide range of carbon content. He found that turned specimens had practically the same modulus of elasticity and stress at elongations of 0·005, 0·010 and 0·020 in. on 2 in. as " as cast " specimens, but the former had slightly lower values of ultimate stress and percentage elongation. There was no drop of the beam of the testing machine during any test, so that malleable iron has no true yield point, and the author suggests that the term " yield point " and references to the drop of the beam should be deleted from A.S.T.M. specifications, and that the term " proof stress," specified as a percentage of the ultimate stress, might be used.

Changes in Structure During the Process of Rupture in Conjunction with the Characteristic Curves of Materials. T. Pöschl. (Metallwirtschaft, 1940, vol. 19, Apr. 26, pp. 331–335). The author

describes an apparatus which consists of a combination of a tensile-testing machine and a microscope so constructed that the tensile test can be stopped at any desired degree of stress and a micrograph obtained showing the structure of the specimen at that stress.   He presents the stress-elongation diagram of a mild-steel test-piece on which the load was increased very slowly, and reproduces a series of micrographs taken at sixteen successive stages of elongation which demonstrate the process of elastic and plastic flow.

Some Observations on the Yield Point of Low-Carbon Steel.   J. Winlock and R. W. E. Leiter. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, Oct., pp. 581–585). The authors study the yield-point phenomena in a low-carbon steel with a view to determining the mechanism of the transition from the elastic to the plastic state.   They describe a tensile test which provides evidence in support of their theory that uniform elongation does not begin until a load is reached at which all parts of the speci-men are deformed by the same amount as that undergone by that portion of metal which was the first to deform.   In considering the rate of work-strengthening and its relation to the course of the stress-strain curve, the authors point out that so long as both plastic and elastic extension are taking place simultaneously in the test-piece, the true behaviour of the metal in the plastic condition is obscured ; conse-quently their definition of the rate of work-strengthening is '' the rate of increase of only the stress actually necessary to cause further plastic deformation in metal which has already been plastically deformed.''

Improving Drawability of Steel by Controlling Nitrogen.   C. L. Altenburger.   (Metal Progress, 1940, vol. 37, June, pp. 639–643). The author discusses the results of tensile tests on specimens of steel sheet the object of which was to study the influence of different heat treatments on the blue-brittleness and strain-ageing pheno-mena.   He observed that rimmed Bessemer steel sheet strain-ages much more than rimmed open-hearth steel sheet.   He also found that by taking special care to exclude traces of nitrogen when annealing steel sheet in hydrogen, reproducible relationships between the tensile strength and the temperature of testing could be obtained, and a specimen of steel sheet with a desired tensile strength, within certain limits, at a given temperature could be prepared by con-trolling the annealing temperature and the time of holding at that temperature.   The author's conclusion is that the strain-ageing properties of steel sheet are affected by the movement of nitrogen out of the steel while it is being annealed in hydrogen.   Finally he discusses the effect of zirconium in steel on the tensile strength, elongation and reduction of area at different temperatures.

New Strain Measurement Method Offers Unusual Possibilities. (Steel, 1940, vol. 107, July 1, pp. 57, 68).   A brief description is given of a strain gauge which consists of a short length of a special electrical conductor cemented to the specimen the elongation of which is to be measured.   As the resistance of the conductor

changes with the strain, the measurement of the changes in resistance by means of a suitable potentiometer circuit provides a method of determining the strain. It is claimed that measurements can be made to within one-millionth of an inch. The effective gauge length is 1 in. and the device can be used on stationary or moving parts wherever it is possible to cement the gauge in place.

Plastic Deformation of Mild Steel Bar Due to Combined Tension and Torsion. M. Nakahara. (Transactions of the Society of Mechanical Engineers, Japan, 1940, vol. 6, Feb., pp. I-7–I-12). (In Japanese). In a mathematical discussion the author develops a formula for determining the direction of the plastic slip in a steel bar under combined tensile and torsional stresses.

Calculation of Stresses Within the Boundary of Photo-Elastic Models. R. Weller and G. H. Shortley. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, June, pp. A-71–A-78). The authors propose a method for the determination of the internal stresses in a two-dimensional system from data furnished by a photo-elastic analysis. The method involves the numerical integration of the Laplace difference equation over a region with known boundary values by the integration of a set of improvement formulæ.

ǀ **The Maybach Strain-Lines Process and Its Application to Metals.** O. Dietrich. (Metallwirtschaft, 1940, vol. 19, Apr. 26, pp. 337–342). The author describes the application of the Maybach strain lines for the detection of stress concentrations in assemblies of metal parts such as motor-car frames. The details of the system itself are not given, but the strain lines are shown up by special varnishes applied to the parts.

Stresses in Helical Compression Springs—Present Status of the Problem. C. T. Edgerton. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, Oct., pp. 643–648). In a mathematical discussion the author compares the formulæ of Röver, Wahl, Adams, Gohner, Vogt and Perkins for calculating the stresses in helical springs, and points to discrepancies between theory and practice which indicate the need for further research.

Analysis of Effect of Wire Curvature on Allowable Stresses in Helical Springs. A. M. Wahl. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, Mar., pp. A-25–A-30). In this mathematical treatise the author suggests a method for determining the effect of the curvature of the wire or bar on the permissible stresses in helical springs. (*See* Journ. I. and S.I., 1939, No. I., p. 295 A).

The Interpretation of a Failure of an Ordnance Structure. G. F. Jenks. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, Apr., pp. 191–196). The author describes an investigation of the cause of failure of the barrel of a 240-mm. howitzer after firing only 283 rounds. An examination of the flow lines at the rupture revealed the manner in which the crack had

grown and indicated the position of the source. Acid-etching and a microscopic examination established that the cause of the failure was a weld of inferior quality which had been applied to cover an error in machining.

A New Fatigue Tester and Testing of the Tempered Steel. Y. Kidani. (Transactions of the Society of Mechanical Engineers, Japan, 1940, vol. 6, Feb., pp. I-36–I-40). (In Japanese). The author describes a new torsional fatigue testing machine of the resonance type suitable for small specimens.

A Pulsating Tension-Fatigue Machine for Small Diameter Wire. J. N. Kenyon. (American Society for Testing Materials, June, 1940, Preprint 35). The author describes a tension-fatigue testing machine employing three reciprocating forces 120° out of phase. The machine is intended for testing new or used steel wire of small diameter. The minimum, mean and maximum loads are all positive, so that the wire does not buckle, and a special method of gripping has been devised which ensures that over 80% of the specimens tested fracture at a position clear of the end connectors.

Fatigue of Porous Metals. C. G. Goetzel and R. P. Seelig. (American Society for Testing Materials, June, 1940, Preprint 34). The authors report on an investigation of the fatigue strength of specimens of copper and iron made by the powder-metallurgy process, the object being to assess the effect of different degrees of porosity. The porosity was varied by using powders of different grain size and by compressing at different pressures. The specimens were tested in a Moore and Wishart fatigue-testing machine and stress/number-of-cycles curves were plotted and compared with those for cast copper and ingot iron. It was found that the total porosity, not the size of the individual pores, had the more important effect and that the fatigue limit decreased with increasing total porosity ; this reduction was, however, less than that expected.

Fatigue Strength of 2-in. Diameter Axles With Surfaces Metal Coated and Flame Hardened. O. J. Horger and T. V. Buckwalter. (American Society for Testing Materials, June, 1940, Preprint 32). The authors report on an investigation of the fatigue strength of steel axles with and without press-fitted flywheels, and on the effect on the fatigue strength of metal-spraying and flame-hardening the axle prior to fitting the wheel. The axles were of steel S.A.E. 1045 normalised and tempered. The metal sprayed on was from steel wires containing 0·40% and 1·20% of carbon. In general, the results showed that there was little difference in the endurance limits of the plain and the sprayed axles, whilst the sprayed and flame-hardened axles had a much higher endurance limit than the untreated axles.

Hardness Conversion for Hard Metals. T. H. Gray and H. Scott. (Iron Age, 1940, vol. 145, June 6, pp. 39–41). The authors present a number of equations for the conversion of one Rockwell hardness scale to another as well as to diamond-pyramid hardness

units. They also present a hardness conversion table for diamond-pyramid hardness numbers from 1040 down to 200 in steps of 20 points, from which the equivalent Rockwell C and A numbers, the Rockwell superficial hardness, the scleroscope hardness and the Monotron load scale values can easily be obtained. In a second table the equivalent diamond-pyramid and Rockwell hardness values for sintered carbides in the range 1750–900 diamond-pyramid hardness are given. These tables are not subject to the clause " approximate only " but can be considered as accurate when restricted to metals of the same elastic modulus.

High Hardenability and Toughness in Carbon and Low Alloy Steels. J. Strauss. (Metals and Alloys, 1940, vol. 11, June, pp. 174–176). The author refers to the general conclusion arrived at after much research on the relation between the grain size and the hardenability of steel, namely, that fine grain size is associated with shallow hardening and toughness, and coarse grain size with deeper hardening and less toughness. To deal with this position grain-refining practice with or without the addition of fairly substantial amounts of alloying elements has been introduced. He then discusses the properties of a series of steels called " Grainal-treated " which are produced by making small additions of a ferro-alloy containing vanadium, titanium and aluminium in the final stages of the steelmaking process. Only about 2–5 lb. of the alloy per ton of steel are added, and the results of numerous tests demonstrate the marked improvement in the tensile, impact and hardness properties of the steels prepared in this way.

Wear in Lubrication Problems. L. M. Tichvinsky. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, May, pp. 335–342). The author describes and reviews the development since 1905 of machines for the measurement of the wear under conditions of sliding friction between two metal surfaces in contact and of wear caused by applying an abrasive to a metal surface.

Choice of Tool Steels According to Their Wear-Toughness. H. B. Chambers. (Metal Progress, 1940, vol. 37, June, pp. 665–670, 692). The author proposes a method of classifying tool steels which is based on the relation between wear and toughness and is intended to facilitate the selection of a suitable steel for a particular operation. He presents a data sheet in which the steels are divided in the following three groups : (a) Water-hardening steels ; (b) oil- and air-hardening steels ; and (c) high-speed steels and steels for hot-working. The analyses, conventional names, wear and toughness properties and usual applications are given.

Some Experiments on Seizure Between Lubricated Hard Steel Balls. D. Clayton. (Journal of the Institute of Petroleum, 1940, vol. 26, May, pp. 256–271). The author reports on an investigation of the mechanism of seizure of hard steel balls to ascertain the effect of changes in the test conditions. The four-ball apparatus

previously described was used (*see* Journ. I. and S.I., 1940, No. I.,
p. 285 A), but in the present investigation the speed was varied, an
increasing-load test was tried, the seizure was interrupted and the
rigidity of the chuck mounting was varied. In tests with con-
tinuously increasing load, the breakdown loads for mineral and fatty
oils were 40% higher than in tests at a series of constant loads ; the
wear values corresponded with those found in previous tests for the
particular loads. Tests at half and double the normal speed showed
that with increase of speed the breakdown load decreased, the time
to seizure decreased, and the wear generally increased. Using a
mineral oil and interrupting the seizure by removing the load showed
that most of the wear occurred in the early part of the seizure period ;
on restoring the load, even after several minutes, the friction im-
mediately rose to its high value again. This test showed that the
continuance of high friction with this type of oil was not merely due
to high temperature at the contact persisting from the early part of
the failure. Considerable increase of load could be made after
recovery before a second seizure resulted.

**On the Elastic Moduli of Ferromagnetic Materials. Part I.
Dynamical Measurements of the Elastic Moduli of Iron Crystals.
Part II. The Change in Young's Modulus due to Magnetisation and
Temperature. Part III. ΔE-Effect of Iron Single Crystals. Part
IV. ΔE-Effect of Iron Single Crystals at High Temperature. Part V.
The ΔE-Effect of Iron Single Crystals at High Temperature (Continued)
and the ΔK-Effect.** R. Kimura. (Proceedings of the Physico-
Mathematical Society of Japan, 1939, vol. 21, Nov., pp. 686–706 ;
Dec., pp. 786–799 ; 1940, vol. 22, Jan., pp. 45–60 ; Feb., pp. 219–
250). The Young's modulus and the rigidity modulus of single
crystals of iron were determined by a dynamic method in which the
torsional vibration of the specimen rod was excited magnetically,
and the coincidence of the frequency of the exciting current with the
natural frequency of the rod was detected by the change in the im-
pedance of the coil wound around the specimen. The values of
Voigt's moduli were then calculated from the elastic moduli thus
obtained. In subsequent experiments the changes in the Young's
modulus and the rigidity modulus of nickel, cobalt, iron and carbon
steel in magnetic fields of different strength and at different tem-
peratures were investigated.

Transformer Steel Takes a New Turn. W. E. Ruder. (Steel,
1940, vol. 106, June 3, pp. 58–60). The author describes briefly the
use of silicon steel for transformer cores, pointing out how advantage
is taken of the fact that this material carries magnetic flux much
better in the direction of rolling than in other directions. He refers
to a silicon-steel strip developed by Goss and Freeland which
can be cold-rolled. This strip proved difficult to wind round a coil
without straining the metal. Finally, he describes with diagrams
a simple and effective method, perfected by Granfield, of winding
silicon-steel strip round an insulated transformer coil without

damaging the insulation or imposing mechanical stresses on the strip.

The Automatic Maintenance of Load in Creep Testing. G. A. Mellor and E. A. Jenkinson. (Journal of Scientific Instruments, 1940, vol. 17, June, pp. 155–156). A description is given of an apparatus designed and in use at the National Physical Laboratory, which forms a valuable auxiliary to a creep-testing unit. In this unit there is a 10 : 1 lever arm carrying the load and the end of this arm falls as the specimen creeps. The device, the mechanical details of which are described and illustrated, provides a means of maintaining the lever arm in its horizontal position as the specimen extends, so that tests can continue for long periods with the minimum of attention.

Effects of Temperature of Pretreatment on Creep Characteristics of 18–8 Stainless Steel at 600° to 800° C. C. R. Austin and C. H. Samans. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1181 : Metals Technology, 1940, vol. 7, June). The authors refer to a previous investigation of the creep of a number of alloy steels at 600°, 700° and 800° C. (*see* Journ. I. and S.I., 1938, No. I., p. 177 P) in which the preliminary heat treatment of the specimens consisted of holding for 15 min. in hydrogen at 950° C. followed by cooling in air. In the present paper they describe a similar investigation of 18/8 steel specimens prepared in three different ways by holding for 15 min. in hydrogen at 1150° C., 950° C. and 750° C. respectively, followed by cooling in air. These treatments permitted two comparisons to be made : (1) Between the 1150° and 950° C. treatments, to indicate the effect of grain size when all the carbides were probably in solution at the commencement of the creep test ; and (2) between the 950° and 750° C. treatments, to indicate the effect of carbide nucleation for similar grain sizes. The more important conclusions arrived at are : (1) In confirmation of the work of previous investigators, an increase in the grain size increases the resistance to deformation of 18/8 stainless steel only at the higher test temperatures ; (2) the temperature above which the increase in grain size becomes effective is 600–700° C. ; (3) creep tests at below 600° C. indicate that the temperature of pretreatment has no material effect on the creep characteristics ; (4) at 600° and 700° C. the process of carbide-precipitation of 18/8 steel is relatively slow and apparently proceeds for several thousand hours ; (5) precipitation seems to occur preferentially in the following places : at the grain boundaries, at the ends and sides of twin bands, and within the grain ; (6) two types of precipitate occur, one probably carbide and the other, slightly pink in colour, probably ferritic in nature ; and (7) neither the stress nor the plastic deformation accompanying it, in the range studied, seems to have any effect on the character of the carbide precipitate.

The Creep Strength of 17 Low-Alloy Steels at 1000° F. R. F. Miller, W. G. Benz and W. E. Unverzagt. (American Society for

Testing Materials, June, 1940, Preprint 45). The authors report on an investigation of the creep strength of a number of low-alloy steels. The steels were divided into the three following groups containing : (a) Up to 2% of molybdenum ; (b) up to about 1% of molybdenum and up to 3·26% of chromium ; and (c) up to 1% of molybdenum and about 5% of chromium. Four of the steels contained small amounts of aluminium, titanium or niobium. The results demonstrated that the creep strength of carbon-molybdenum steel increases with increasing molybdenum content in both the normalised and the normalised and tempered condition. For each composition, the creep strength is higher after normalising than after normalising and tempering. The addition of manganese slightly increases the creep strength of normalised and tempered steel containing about 0·5% of molybdenum. The addition of chromium tends to lower the creep strength of molybdenum steels, but the chromium increases the stability of their structure. The creep strength of chromium-molybdenum steels is adversely affected by the addition of silicon and aluminium. The addition of titanium or niobium to chromium-molybdenum steel improves its creep strength in the hot-rolled and tempered condition.

High Temperature Rupture and Creep Tests. E. L. Robinson. (American Society for Testing Materials, June, 1940, Preprint 48). The author discusses the interpretation of the results of long-time creep tests and the danger of extrapolating the results of 10,000 hr. tests in order to obtain the creep of steel after 100,000 hr.

High-Speed Tension Tests at Elevated Temperatures. M. Manjoine and A. Nadai. (American Society for Testing Materials, June, 1940, Preprint 44). With the object of obtaining information to assist research on the true linear rates of stretching in hot-rolling and drawing operations, the authors developed a high-speed tensile testing machine in which the specimen is placed at the axis of a copper coil forming an induction furnace with which temperatures of up to 1200° C. could be attained. In this machine the tensile stresses are applied to the specimen by means of projections on the sides of two flywheels driven by a D.C. motor, and stress-strain curves are automatically recorded on the screen of a cathode-ray oscillograph. The machine is described in detail with drawings and illustrations, and the results of tests on copper specimens are given. Specimens of steel, very pure iron and aluminium have been tested, but the results are not reported in this paper.

Some Effects of Composition and Heat Treatment on the High Temperature Rupture Properties of Ferrous Alloys. R. H. Thielemann. (American Society for Testing Materials, June, 1940, Preprint 46). The author reports on the results of sustained-load rupture tests on fifteen alloy steels at temperatures in the range 900–1300° F., using an apparatus previously described by the author and Parker (see Journ. I. and S.I., 1939, No. II., p. 102 A). The steels tested contained one or more of the following alloying elements :

chromium, nickel, molybdenum, tungsten and niobium. Both transcrystalline and intergranular fractures were encountered, and the author noted that the only alloys not susceptible to failure with the former type of fracture at elevated temperatures were the chromium-bearing ferritic alloys. Micrographs of the structure of fractured specimens showed that plastic deformation resulting in ductile transcrystalline fractures takes place by a process of slip along certain crystallographic planes ; the relief of strain-hardening, by continual recrystallisation with time, allows this type of deformation to progress. If the resistance of the polycrystalline grains to continual deformation by slip is greater than the resistance of the grain boundaries to separation, intergranular fractures will result ; higher temperatures and lower strain rates favour the occurrence of this type of fracture. With the nickel-chromium austenitic alloys, brittle intergranular fractures are encountered even in tests of only a few hours duration. The author explains a system of relating the susceptibility to failure by intergranular cracking of an alloy to its composition.

The Resistance to Relaxation of Materials at High Temperature. E. L. Robinson. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, Aug., pp. 543–550). After a discussion of the general characteristics of relaxation tests which have been previously described (*see* Journ. I. and S.I., 1939, No. I., p. 114 A), the author presents several series of graphs which illustrate the trend of the results of numerous relaxation tests at 750° and 850° F. on bars and tubes of S.A.E. 4140 steel and of molybdenum and chromium-molybdenum steel.

Effect of High Temperatures and Pressures on Cast Steel Venturi Tubes. W. S. Pardoe. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, Apr., pp. 247–248). The author presents the results of tests of the expansion in the main and throat diameters of cast-steel venturi tubes subjected to dry heat and to pressure. From these data he calculates the coefficient of expansion and the modulus of elasticity.

High-Temperature-Steam Experience at Detroit. R. M. van Duzer, jun. and A. McCutchan. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, July, pp. 383–398). The authors report on an examination of certain parts of the 10,000-kW. steam turbine which was erected for the Detroit Edison Co. in 1933 and dismantled in 1937 after over 26,000 hr. of service, most of which was with steam at 1000° F. A study of the principal materials used in its construction, as well as for the tubing and superheater, showed that, with some exceptions, the alloy steel used were in good condition and that the amount of creep had been very small.

The Strength of Steel and Cast Iron. M. G. Corson. (Iron Age, 1940, vol. 145, June 20, pp. 32–35). The author discusses how the strength of steel varies in relation to the amounts of silicon, carbon

and manganese contained in it. He contends that the structural characteristics of a given steel are incidental to, but not the causes of, its particular tensile strength. According to this theory, every carbon alloy of iron is precipitation-hardened even if it is subjected to a spheroidising anneal for days, but it is only that carbide precipitate which remains invisible which accounts for the additional strength, so that any specific state of steel is characterised by the amount of carbide still remaining in the ultra-microscopic state. He suggests that the precipitates are in the form of filaments, not particles. He also proposes a formula for indicating the change of strength produced by the addition of a unit quantity of carbon, manganese, silicon or phosphorus. In conclusion he applies his theories to cast iron, taking into account the complication arising from the presence of graphite flakes and gives an approximate formula to represent the weakening effect of graphite flakes.

Mechanical and Physical Properties of High Duty and Alloy Cast Irons. J. W. Donaldson. (Metal Treatment, 1940, vol. 6, Summer Issue, pp. 51–57, 61). After discussing the British Standard Specifications for grey and high-duty iron castings (No. 321 and No. 786), the author reviews the properties of a large number of high-duty and alloy cast irons as determined by the American Society for Testing Materials, the Research Committee of the Institution of Mechanical Engineers and by other authorities in the United States, Britain and Germany. The cast irons dealt with include Ni-Tensyl and iron alloyed with chromium and copper ; chromium and nickel ; nickel, chromium, copper and molybdenum ; nickel and molybdenum ; and nickel, chromium and copper.

Chromium Heat-Resisting Cast Irons. R. C. Tucker. (Institute of British Foundrymen, June, 1940, Paper No. 706). The author reviews the present state of knowledge of heat-resisting cast irons with special reference to those containing chromium. He describes and illustrates some examples of retort castings containing 0·6–0·65% of chromium which have given good service at temperatures up to 950° C. In discussing the properties of the high-alloy cast irons, the author deals mainly with Nicrosilal, Ni-Resist and Cralfer.

Properties of Commercial Pearlitic Malleable Iron. C. H. Lorig. (American Society for Testing Materials, June, 1940, Preprint 38). The author endeavoured to correlate the mechanical properties of a large number of pearlitic malleable irons of American manufacture. The irons were rendered pearlitic either by a special heat treatment or by the addition of alloying elements. He established that close relationships exist between the Brinell hardness, the tensile strength and the yield point, and that these are independent of the method of manufacture and are not greatly affected by the character of the iron-carbide particles.

CORROSION OF IRON AND STEEL

A Method of Measuring Corrosiveness. J. H. Walker. (American Society for Testing Materials, June, 1940, Preprint 104). The author describes a device for measuring the corrosiveness of water and condensates in steam heating systems. The device consists of three helical coils of Bessemer steel wire, 0·05 in. in dia., mounted on a frame which can be inserted in the pipes of the system. After about 28 days exposure the frame is taken out, the products of corrosion are removed by an acetic acid solution containing an inhibitor, and the loss in weight is determined. The three coils are of the same dimensions and the average loss in weight is taken as an indicator of the corrosiveness of the condensate. The advantages and limitations of the device are discussed.

Atmospheric Durability of Steels Containing Nickel and Copper. N. B. Pilling and W. A. Wesley. (American Society for Testing Materials, June, 1940, Preprint 28). The authors report the results of several series of corrosion tests on the life of copper-bearing and nickel-copper-bearing steel sheets in rural, marine and industrial atmospheres, in soil and in coal wagons. The copper-bearing steels contained up to 2% of that element and the copper-nickel steels contained up to 10% of both elements in a variety of proportions. In general the results clearly showed the beneficial effect of nickel on the corrosion-resistance of steel and that this effect increased with increasing nickel content. This beneficial effect was enhanced by the addition of copper, but the amount of copper should be less than the amount of nickel. The manganese, silicon and carbon contents did not appear to be of importance, but a moderate amount of phosphorus had a beneficial effect.

Outdoor Exposure Tests of Electroplated Nickel and Chromium Coatings on Steel and Nonferrous Metals. W. Blum and P. W. C. Strausser. (Journal of Research of the National Bureau of Standards, 1940, vol. 24, Apr., pp. 443–474). The authors present the results obtained since 1936 from atmospheric corrosion tests on coatings of copper, nickel and chromium, separately and combinations of these, on steel, copper, brass and zinc. Specimens were exposed at Key West, New York, Pittsburgh, Sandy Hook, State College (Pennsylvania), and Washington. The general conclusions reached were as follows : (1) The most important factor in the protective value of nickel and chromium coatings on steel, brass or zinc is the thickness of the nickel layer ; (2) on steel or zinc, a layer of copper under the nickel adds little to the protective value of thin coatings ; (3) with

thick deposits the protective value of a composite coating approaches, but does not exceed, that of a nickel coating of the same total thickness ; (4) variations in the methods of preparing the surface and of nickel-plating have no important effect upon the protective value ; and (5) variations in the thickness of a chromium coating within the range 0·00001–0·00003 in. applied over nickel have very little effect, but if the variation is 0·00005 in. or more, cracking is likely to occur.

Electrolytic Corrosion of Stainless Steels. E. Maurer. (Iron and Coal Trades Review, 1940, vol. 140, June 28, pp. 933–934). An abridged English translation is presented of the author's paper on the attempted application of time-potential curves for the assessment of the corrosion resistance of chromium-nickel and chromiummanganese steels. The paper appeared originally in Korrosion und Metallschutz, 1939, vol. 15, Sept., pp. 285–294. (*See* Journ. I. and S.I., 1940, No. I., p. 107 A).

The Effect of Protective Coatings on the Corrosion-Fatigue Strength of Steel. T. J. Dolan and H. H. Benninger. (American Society for Testing Materials, June, 1940, Preprint 30). In order to investigate the relative efficiencies of protective coatings in increasing the corrosion-fatigue strength of steels, the authors carried out laboratory tests with the following materials : (1) A heat-treated and tempered S.A.E. 3140 steel with a thin electroplated coating of (*a*) cadmium and (*b*) zinc ; (2) the same steel with a cyanided surface ; (3) steel S.A.E. 1020 with a silicon-impregnated case ; and (4) steel S.A.E. 6120 with a nitrided case. All the specimens were subjected to completely reversed cycles of flexural stress while in contact with fresh tap water. It was found that the corrosion-fatigue endurance limits for all the above materials except steel (3) were considerably below the endurance limits of the uncoated material in air. Specimens of steel (3) exhibited the same endurance limits in air and in water. The zinc-plated specimens had a somewhat higher corrosionfatigue endurance limit than the cadmium-plated specimens, but both materials had endurance limits less than 45% of that of the uncoated material in air. The nitrided case was very efficient in resisting pitting due to corrosive attack and the corrosion-fatigue endurance limit of these specimens was the highest obtained.

Attack on Steel in High-Capacity Boilers as a Result of Overheating Due to Steam Blanketing. E. P. Partridge and R. E. Hall. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, Oct., pp. 597–621). The authors describe a type of failure in boiler tubes which has been found to be common to a number of water-tube boilers operating at pressures of 1200–1400 lb. per sq. in. In general, the failure has occurred in tubes slightly inclined to the horizontal, and examination has revealed internal corrosion along the top, usually in grooves and with the production of black magnetic iron oxide. The authors present the case histories of a number of these failures and deduce from them that the fundamental cause is that as the steam and water pass along the

tube the former rises and forms a layer between the surface of the water and the top of the tube ; this causes the top of the tube to be more or less seriously overheated, and in that condition it is much less resistant to the attack of the feed water, especially if the latter contains sodium hydroxide. In conclusion the authors suggest that the wasting away of the metal in the manner described may be greatly reduced by eliminating any sodium hydroxide and operating with water containing trisodium phosphate. The real cure for the trouble is a matter of design, however, and boilers should be so constructed that where slightly inclined tubes are subject to a high rate of heat input, these must be protected so that the rate is sufficiently low to prevent excessive overheating of the metal.

An Accelerated Spray Test for the Determination of the Relative Atmospheric Corrodibility of Ferrous Materials. T. Swinden and W. W. Stevenson. (Iron and Steel Institute, 1940, this Journal, Section I.). The development of a method of automatic accelerated spray testing is described, in which the specimens, on an endless belt, complete a cycle of treatment, consisting of spraying, followed by drying in air and in a warm chamber. The cycle is completed in 7 min. and the specimens are subjected to 60 cycles per day. A standardised douching with water is given at the commencement of the second and subsequent days and the daily spraying and drying treatment is carried on for 20 days. Comparative results of long-period field tests and spray tests are given for 14 irons and steels of the low-alloy constructional type. Good agreement is shown in the orders of merit obtained in one-year field tests and in the 20-day spray tests, using a spray liquid consisting of $N/100$ sulphuric acid and $N/100$ sodium chloride. Less satisfactory agreement is shown in field tests and spray tests using $N/100$ and $N/20$ sulphuric acid. It is suggested that the results obtained with the sulphuric-acid/sodium-chloride solution are of sufficient promise to encourage other workers to re-examine the spray method as the basis of a satisfactory short-time laboratory corrosion test.

Changes in a High-Pressure Drum to Eliminate Recurrence of Cracks Due to Corrosion Fatigue. A. E. White. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, Aug., pp. 507–516). The author describes an investigation of the causes of cracks in a drum of one of the water-tube boilers at a power station of the Boston Edison Co. The boiler operated at $725°$ F. and 1400 lb. per sq. in. and had been in almost continuous service from 1927 to 1938. The cracks were found in the wall of the drum at the feed inlets as well as in the flanges and T fittings of the inlets and outlets to the superheater headers. The cracks were not due to faulty material, but the cause was thought to be corrosion-fatigue resulting from stresses set up by changes in temperature at the surface of the metal which was at times in contact with water of a relatively low pH value.

ANALYSIS

A New Method for the Volumetric Determination of Iron. F. R. Bradbury and E. G. Edwards. (Journal of the Society of Chemical Industry, 1940, vol. 59, May, pp. 96–98). The authors describe a direct method for the volumetric determination of iron which is based on the reduction of ferric iron by mercurous nitrate in the presence of an excess of ammonium thiocyanate. The completion of the reduction is marked by the disappearance of the red colour of ferric thiocyanate. The method is shown to be accurate for the determination of both ferric iron and total iron following the permanganate titration of ferrous iron. The authors intend to develop their method so as to render it suitable for the industrial analysis of ferrous alloys.

A Rapid Volumetric Method for Estimation of Iron and Titanium and Its Application to Ilmenite Analysis. P. R. Subbaraman and K. R. Krishnaswami. (Proceedings of the Indian Academy of Sciences, 1940, vol. 11, Section A, Feb., pp. 106–115). The authors describe a rapid volumetric procedure for the estimation of iron and titanium by titration with solutions of ferric sulphate and potassium permanganate, and its application to the analysis of ilmenite.

The Chemical Analysis of Alloy Cast Iron. E. Taylor-Austin. (Journal of the Birmingham Metallurgical Society, 1940, vol. 20, June, pp. 41–60). The author reviews the changes in the procedure for the analysis of cast iron which have become necessary in recent years owing to the development of alloy cast irons. In addition to changes brought about by added elements, certain methods have been superseded by others which are either more rapid or more accurate than their predecessors. An important feature is the introduction of organic reagents into quantitative inorganic analysis. After making general observations, the author notes some effects of alloy additions on the recognised procedures for the determination of the common constituents of cast iron (*i.e.*, total carbon, graphitic carbon, silicon, manganese, sulphur, phosphorus, nickel, chromium and copper). He deals at some length with methods of determining molybdenum, aluminium and titanium, and of separating titanium from vanadium. He considers more briefly the elements tungsten, cobalt, zirconium, tantalum, niobium, arsenic, antimony and tin. In conclusion he points out some advantages derived from the use of organic reagents, amongst which is the fact that owing to the high molecular weight of the organic portion of their metallic complexes they form very copious precipitates ; this enables small amounts of metals to be detected and determined with great accuracy.

Detection of Aluminium in Steel with Aurin Tricarboxylic Acid.
L. P. Adamovich and A. Ya. Zagorul'ko. (Zadovskaya Laborator-
iya, 1939, No. 12, pp. 1315–1316). (In Russian). The authors
describe a method by which aluminium, when present in steel in
excess of 0·05%, can be detected from a single test, using aurin
tricarboxylic acid as a reagent. If the quantity is in the range
0·01–0·05% a blank test is necessary.

Magnetic Determination of Carbon in Steel. H. K. Work and
H. T. Clark. (Engineer, 1940, vol. 170, July 19, pp. 46–47). A
brief description is given of an instrument called a " carbanalyzer "
which applies magnetic principles in order to make rapid determina-
tions of carbon in steel. (See Journ. I and S.I., 1940, No. I.,
p. 214 A).

**Rapid Determination of Copper by α-Benzoin Oxime in Ferromolyb-
denum, Calcium Molybdate, Etc.** L. Silverman. (Industrial and
Engineering Chemistry, Analytical Edition, 1940, vol. 12, June,
pp. 343–344). The author describes a rapid method of determining
small percentages of copper in ferro-molybdenum, ferro-tungsten,
molybdenum steels and calcium molybdate, in which α-benzoin
oxime is used as a reagent for the copper in ammoniacal solution.

**The Determination of Phosphorus in Vanadium Steel and Ferro-
Vanadium.** S. H. Gutman and V. V. Eremichev. (Zavodskaya
Laboratoriya, 1939, No. 12, pp. 1218–1222). (In Russian). Ex-
ploratory experiments on the determination of phosphorus in steels
in the presence of vanadium by the volumetric molybdate method
showed that the procedure giving the best results was to eliminate
the effect of pentavalent vanadium by reducing it with hydroxyl-
amine hydrochloride. Other reducing agents which have been
recommended for the purpose were found to be less satisfactory.
The method is also suitable for the determination of phosphorus in
ferro-vanadium.

**Studies in Spectrographic Analysis. I. Description of the Equip-
ment, Technique and Applications of Spectrographic Analysis in the
Dominion Laboratory.** S. H. Wilson. (New Zealand Journal of
Science and Technology, 1940, vol. 21, Mar., pp. 225B–240B).
The author describes the spectrographic laboratory at the Depart-
ment of Scientific and Industrial Research, Wellington, New Zealand,
where a Hilger automatic large quartz spectrograph has been in-
stalled. He also gives an account of modifications in technique that
have been found useful with this instrument. The methods in use
for the excitation of spectra are the spark, the intermittent arc
with high-frequency pilot, and the direct-current arc on graphite
electrodes. The applications of the apparatus have been for
general laboratory work including the examination of metals for
freedom from harmful impurities, the investigation of corrosion
problems and the determination of metals in waters.

The Spectroscopic Analysis of Steels. A. Fisher. (Wild-Barfield
Heat-Treatment Journal, 1940, vol. 4, June, pp. 2–6). The author

explains the principles and practical application of the spectroscope for making rapid determinations of the elements in steel. As there is great difficulty in obtaining reliable data on the complete iron spectrum in the visual region, he presents a table with a list of all the iron lines seen in the electric arc between the wave-lengths of 4181 Å. and 5662 Å. together with the relative intensities.

The Use of Ultra-Filtration for the Determination of Silica in Slags. A. L. Davydov and E. I. Kochugova. (Zavodskaya Laboratoriya, 1939, No. 12, pp. 1308–1312). (In Russian). A method of determining the silica in blast-furnace slags in which the silica is collected on gelatine-impregnated filter paper hardened with formaldehyde is described. The filtration and washing of the precipitate take only 10–15 min.

A Rapid Method for the Simultaneous Determination of Sulphur and Chlorine in Coal and Coke. A. E. Beet and R. Belcher. (Fuel in Science and Practice, 1940, vol. 19, Mar., pp. 42–45). The authors describe a rapid method (requiring less than 30 min.) for the simultaneous determination of sulphur and chlorine in coal and coke. In this method the sample (up to 1 g.) is placed in a boat and pushed gradually into the hottest zone of a pythagoras combustion tube into which oxygen is passed and where a temperature of about 1300° C. is attained. The chlorine is liberated in its elemental form and is absorbed in a hydrogen peroxide solution. The sulphuric acid formed is titrated with sodium hydroxide using the mercuric oxy-cyanide method of Vieböck.

BOOK NOTICES

ASSOCIATION OF BRITISH CHEMICAL MANUFACTURERS. "*Directory of British Fine Chemicals Produced by Members of the Association.*" 8vo. Pp. 79. London, 1940 : The Association.

This is an up-to-date list of fine chemicals manufactured in Great Britain. The present publication supersedes the edition published in April, 1935, and is distributed gratis to bona fide users of fine chemicals on direct application to the Association at 166 Piccadilly, London, W.1. While the list is representative of the fine chemicals made in this country, and is fairly comprehensive, it must not be assumed that it is in any way exhaustive, as chemicals which are only of very infrequent demand have not been included, though their preparation may have been undertaken, or can be, if required. Again, in view of the limitation of space, numerous salts, especially of the alkaloids, have not been detailed ; the more common of these salts are, however, usually available from stock, and others can be prepared at a few hours' notice. All the fine chemicals listed are actually manufactured in this country, and are generally obtainable at short notice ; there are, however, certain chemicals in the list a permanent supply of which cannot be guaranteed unless there is a sufficient demand.

LONDON AND CAMBRIDGE ECONOMIC SERVICE. Special Memorandum No. 49. "*The Iron and Steel Industry, 1926–1935. An Investigation Based on the Accounts of Public Companies.*" By R. H. Coase, R. S. Edwards and R. F. Fowler. 4to. Pp. 31. Cambridge : London and Cambridge Economic Service.

The investigation on which this Memorandum is based was undertaken with two main objects : first, to indicate the possibilities of using published accounts as a source of economic statistics ; secondly, to show how these statistics can be employed, not only for business forecasting, but also for checking the reality of some of the assumptions of economic theorists and for revealing relationships which ought to be taken into account in, for example, analyses of the trade cycle. The survey differs from others in that it attempts to make use, not only of the profit figures, but also of those relating to assets and liabilities. The following is a synopsis of the contents :

Part I. The General Results. The sample ; size classification ; industrial classification ; the results ; profits and losses ; undistributed profits ; liquid balances and gross working capital ; fluctuations in the demand for liquid balances ; stocks and work in progress ; net trade indebtedness ; bank advances.

Part II. Some Special Aspects. Iron and steel profits and published indices ; the re-investment of profits ; factors determining the demand for bank advances ; the demand for liquid balances ; representative behaviour and the investment of working capital.

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THOMPSON, LILIAN GILCHRIST.   " *Sidney Gilchrist Thomas.   An Invention and its Consequences.*"   8vo, pp. 328.   Illustrated.   London, 1940 : Faber and Faber, Ltd.   (Price 12*s.* 6*d.*)   [See notice, p. 130 A.]

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MINERAL RESOURCES

Geology of the Chromite Deposit of Jojohatu, Singhbhum.
B. S. Bhadauria. (Quarterly Journal of the Geological, Mining
and Metallurgical Society of India, 1939, vol. 11, Sept., pp. 123–132).
The author gives a brief account of the geology of the chromite
deposit of Jojohatu in the hilly portion of Singhbhum, which is the
chief mining locality for the supply of chrome ore to the Tata Iron
and Steel Co., Ltd.

The Occurrence of Ore and the Industrialisation of Finland.
H. F. Geiler. (Metallwirtschaft, 1940, vol. 19, Apr. 26, pp. 343–
346). The author gives a brief account of the occurrence in Finland
of ores containing iron, copper, lead, zinc, gold and silver. The total
iron-ore resources have been estimated at 43,000,000 tons, but only
a very small quantity is worked. The Imatra Works in Vuoksenniska
has a productive capacity of about 40,000 tons of iron per annum,
which covers the major portion of Finnish requirements.

Bentonite : Its Properties, Mining, Preparation and Utilization.
C. W. Davis, H. C. Vacher and J. E. Conley. (United States Bureau
of Mines, 1940, Technical Paper No. 609). A detailed account is
given of the deposits of bentonite in the United States and Canada,
with brief particulars of deposits in other parts of the world. Its
mining, preparation for market, properties, and present and proposed
applications are also discussed. Bentonite is a clay-like substance
formed by the weathering or alteration of volcanic ash ; it has valu-
able cementing properties and is used for imparting plasticity to
clays and refractory materials and as a bonding material for moulding
sand.

REFRACTORY MATERIALS

The Development of Superduty Refractories from Ohio, Pennsylvania and Kentucky Fire-Clays. R. Russell, jun. (Ohio State University Studies, Engineering Series, 1940, vol. 9, Mar., Bulletin No. 105). After discussing the requirements for super-duty refractory bricks, the author gives a detailed account of an investigation of the properties of fireclays occurring in Ohio, Kentucky and Pennsylvania, and then describes the process of manufacturing refractory bricks and the properties of the bricks produced.

Chromite and Chrome-Magnesite Refractories. J. Robitschek and F. Singer. (British Clayworker, 1940, Jan. and Feb., Reprint). The authors describe and discuss the methods of manufacture and the properties of chromite and chrome-magnesite bricks, dealing in turn with the occurrence and analyses of the ores used, the manufacturing processes, industrial applications and future developments.

Refractories Used in High-Frequency Electric Melting of Steel and Alloys. B. W. Magalis. (Bulletin of the American Ceramic Society, 1940, vol. 19, Aug., pp. 298–301). After discussing the properties of an ideal refractory lining for coreless induction furnaces in steel foundries, the author describes the methods which have actually been developed for preparing basic and acid linings for these furnaces.

FUEL

Developments in Coal Research and Technology in 1937 and 1938.
A. C. Fieldner. (United States Bureau of Mines, 1940, Technical
Paper No. 613). The author presents a review of the developments
in coal research and technology which have taken place in the
principal coal-producing countries of the world during 1937 and
1938. There are 667 references to the literature.

A Coal-Cleaning Policy. A. A. Hirst. (Journal of the Institute
of Fuel, 1940, vol. 13, Aug., pp. 221–226). The author discusses the
problems of coal-cleaning which confront the Coal Production
Council recently appointed in Great Britain to devise means of
increasing the output of coal. He suggests methods, adapted to the
present circumstances, of improving the standards of preparation.
In developing the policy outlined in the present paper the author's
purpose was to find the easiest way of achieving the objects of coal-
cleaning, using as far as possible existing separating plant, additions
where necessary being confined to extensions to existing equipment.
After considering the merits and imperfections of various processes
of separation, the author explains the principles of his proposed
policy. These are : (1) The coal-cleaning process should not be
required to operate under conditions in which it is inefficient ; (2)
if inefficient working is unavoidable, the process should be arranged
so that, as far as possible, contamination of the washed products
with " sinks " of higher ash content is confined to products themselves
high in ash, and to fines rather than to nut sizes. He next gives some
examples of the application of this policy to some coal-cleaning
problems, and, in conclusion, discusses some separation problems
involved in the production of pure coal.

Magnetic Separator Development. (Iron and Coal Trades Review,
1940, vol. 141, Aug. 23, pp. 192–193). The design of a number of
magnetic separators is described and illustrated. The separators
referred to are generally used for removing odd pieces of iron and
steel from coal as it passes along a conveyor to a pulverising plant.

**Carbonizing Properties and Petrographic Composition of Poca-
hontas No. 3-Bed Coal from Buckeye No. 3 Mine, Wyoming County,
W. Va. and of Pocahontas No. 4-Bed Coal from No. 4 Mine, Raleigh
County, W. Va.** A. C. Fieldner, J. D. Davis, D. A. Reynolds, L. D.
Schmidt, R. E. Brewer, G. C. Sprunk and C. R. Holmes. (United
States Bureau of Mines, 1940, Technical Paper No. 604).

Assessment of Coking Properties of Coals. A. Shimomura.
(Journal of the Institute of Fuel, 1940, vol, 13, Aug., pp. 247–256).

The author discusses the results that he obtained in the course of his laboratory experiments on the behaviour of over 170 samples of coal on heating. The samples included twenty coals of British origin, the remainder comprising Japanese, Chinese, Indo-Chinese and European coals. He describes preliminary tests regarding the relation of the colour of powdered coal to its caking properties, the Kattwinkel method of determining the caking index and the K-B-S (Kattwinkel-Baum-Shimomura) apparatus for measuring the contraction and expansion of coal on heating. The author divides coking coals into two groups, " soft " and " hard " coals. In the former group are coals or blends which soften and fuse at comparatively low temperatures, and swell considerably without, however, manifesting an appreciable swelling pressure, and which have a temperature of maximum rate of evolution of volatile matter lower than 460° C. A " hard " coal or blend is one which softens and fuses at comparatively high temperatures, swells moderately with a fair amount of swelling pressure, and has a maximum rate of evolution of volatile matter at a temperature higher than 460° C. In his opinion, it is not impossible to convert any " soft " coal into a " hard " one, or into something very near it, by suitable blending.

Dangerously Swelling Coals. (Coke and Smokeless-Fuel Age, 1940, vol. 2, July, pp. 148–151). The Koppers experimental oven for determining the expansion of coal during coking is described, and some of the conclusions arrived at by Russell with regard to the measurement of pressures developed during the carbonisation of coal are discussed. (*See* Journ. I. and S.I., 1940, No. I., p. 4 A).

Plastic Properties of Bituminous Coking Coals. R. E. Brewer, C. R. Holmes and J. D. Davis. (Industrial and Engineering Chemistry, Industrial Edition, 1940, vol. 32, July, pp. 930–934). The authors draw attention to the fact that some high-volatile coals which develop a high degree of fluidity during carbonisation show improved coking characteristics if the coal has been previously oxidised to a degree peculiar to each coal. They then give an account of their experiments on some high-, medium- and low-volatile American bituminous coking coals, in which they determined the plastic properties of samples previously oxidised for various periods in air at 99·3° C. The results, full details of which are given, showed that the coking properties were improved by the oxidation treatment.

The Development of Low-Temperature Carbonisation in Germany. A. Thau. (Coke and Smokeless-Fuel Age, 1940, vol. 2, June, pp. 138–142 ; July, pp. 155–158). In this review of the development of low-temperature carbonisation processes in Germany the author first compares some English and German methods of applying heat to the charge in internally heated ovens. He describes the system adopted by the Kohlergas A.G. in Germany, which makes use of the gas expelled from the coal as a heat-carrier, after it has been freed from tar and light oil, by propelling it through a tubular heater the

tubes of which are heated by gas. In Germany great attention is paid to the ability to produce a tar applicable as a fuel oil without after-treatment other than dehydration. The author then describes the oven constructed by the Brennstoff-Technik A.G., which has been standardised in four different sizes ; as it has movable side walls, coke from expanding coal can be discharged from it without difficulty. He concludes by describing and illustrating the plant used in the Berg, Lurgi, Kohlergas and Pintsch processes of low-temperature carbonisation.

Coal By-Products. Pseudopolymer and Synthetic Aromatic Oils. W. H. Carmody and H. E. Kelly. (Industrial and Engineering Chemistry, Industrial Edition, 1940, vol. 32, July, pp. 954–957). The authors describe means of treating some of the end-products of the high-temperature carbonisation of coal which are usually disposed of by adding them to some types of tar or by burning them as fuel. This end-product is usually called " pure still residue." The treatment now advocated consists of combined steam- and vacuum-distillation to remove the oil-like materials from the more complex and non-volatile portion. The oil produced in this way has been found to represent a mixture of a number of members of a new family of aromatic derivatives, which have been termed " pseudopolymers," the properties of which the authors discuss in some detail.

PRODUCTION OF IRON

Tata Iron and Steel Co., Ltd., Builds a Blast-Furnace. E. T. Warren. (Blast Furnace and Steel Plant, 1940, vol. 28, May, pp. 473–477). The author gives a brief description of a new blast-furnace at the works of the Tata Iron and Steel Co., Ltd., Jamshedpur. The furnace has a volume of 35,160 cu. ft. and is capable of producing 1100 tons of iron per day. It is designed and equipped in accordance with modern American practice.

An Electrically Operated Clay Gun. A. F. Morgan. (Iron and Coal Trades Review, 1940, vol. 141, Aug. 2, pp. 115–116 : G.E.C. Journal, 1940, vol. 11, Aug., pp. 142–145). An illustrated description is given of an electrically operated remote-controlled clay gun for plugging the tap-hole of blast-furnaces. With this gun the hole can be plugged against the flow of iron without shutting off the blast and the entire operation takes only 15 sec.

Manufacture of Low-Silicon Pig Iron Using High Blast Temperatures. C. F. Hoffman. (Proceedings of the Open-Hearth Conference of the American Institute of Mining and Metallurgical Engineers, 1940, pp. 146–150). The author describes the blast-furnace practice at two of the furnaces of the Bethlehem Steel Co. producing a basic iron containing 0·60–0·90% of silicon. It is shown how the use of higher blast temperatures enabled the silicon and sulphur to be kept low and the coke consumption to be reduced.

" Stakhanov " Methods of Operating the No. 3 Blast-Furnace at Zaporozhstal Works. D. Pospelov. (Stal, 1939, No. 10–11, pp. 1–7). (In Russian). The output of the 1300-cu. m. No. 3 blast-furnace of the Zaporozhstal works has been gradually increased from an average of 1551 tons of pig iron per day during October, 1939, to 1586 tons per day during the first twenty days of November. The maximum daily output was 1975 tons. The author describes the working of a furnace crew using " Stakhanov " methods, and gives specimens from the log for the various operations between tappings. The methods adopted to control the working of the furnace are also discussed.

Quality of Iron for Open-Hearth Use. H. W. Johnson. (Proceedings of the Open-Hearth Conference of the American Institute of Mining and Metallurgical Engineers, 1940, pp. 162–167). The author discusses the variables encountered in blast-furnace practice, in particular, how slight variations in the analysis of the ore and the ash content of the coke affect the working of the furnace.

Iron Blast-Furnace Slag Becomes Important Constructional Material. W. H. Caruthers. (Mining and Metallurgy, 1940, vol.

21, July, pp. 337–340). The author describes the methods of dealing with blast-furnace slag in accordance with American practice and its uses and gives some specifications of slag for road-making.

The Viscosity of Primary Blast-Furnace Slags at the Magnitogorsk Works. M. Ostroukhov. (Stal, 1939, No. 10–11, pp. 11–17). (In Russian). The author describes his investigation of the viscosity of the slag from the Magnitogorsk blast-furnaces. In order to avoid reduction, samples of manganese-bearing slag were not heated above 1400° C. in graphite crucibles. Iron-bearing slags had to be tested in iron crucibles in which the temperature was likewise limited to 1400° C. Synthetic slags falling within a triangle on the silica-alumina-lime ternary diagram bounded by the lines connecting the silica 40%, alumina 20% and lime 30% points were studied together with the effect on their viscosity of additions of 3–6% of magnesia, 6% of magnesia with 4–10% of manganous oxide, and of 6% of magnesia with 7–10%, 15% and 30% of ferrous oxide. In addition several slags approximating to eutectic compositions were studied. The data obtained for the viscosities at different temperatures and the temperatures of primary crystallisation are given in tabular form. Additions of magnesia lowered the viscosity of the silica-alumina-lime slags, particularly those containing appreciable amounts of alumina. At the same time additions of magnesia narrowed the crystallisation temperature range. Additions of ferrous oxide also lowered the viscosity of the slags containing magnesia, particularly when present in large amounts, such as 30%. Additions of manganous oxide had a similar effect, which was further increased when this oxide and ferrous oxide were added together. Some of the results obtained for the ternary slags are compared with those of previous investigators including those of McCaffery. In conclusion, observations by the author and by other investigators on the difficulties of measuring the viscosity of slags are dealt with.

Porous Anti-Friction Cast Iron Made From Powder. M. Yu. Bal'shin and N. G. Korolenko. (Metallurgia, 1940, vol. 22, June, pp. 59–61). An abridged English translation is presented of a paper in which the authors describe a method of producing a porous bearing metal by the " powder metallurgy " process from powder produced by grinding cast-iron borings and turnings. The article appeared originally in Vestnik Metallopromyshlenosti, 1939, No. 3, pp. 34–41. (*See* Journ. I. and S.I., 1939, No. II., p. 318 A).

FOUNDRY PRACTICE

Rationalisation Trends in the Foundry Industry. H. Zetterling. (Teknisk Tidskrift, 1940, vol. 70, June 15, Mekanik, pp. 69–70). (In Swedish). The author describes some improvements in foundry equipment which he observed in the course of a visit to German foundries in 1939. One item of interest is a portable mould-drying unit, which consists of a vertical combustion chamber, with a burner in the side which is connected by a flexible tube to the fuel-gas supply main. An electric blower mounted above the combustion chamber drives air down an annular space surrounding the chamber to the opening at the bottom, where this air sucks out and mixes with the products of combustion. The unit is placed over each mould in turn, and the blower is sufficiently powerful to force the hot gases down into the mould.

Prevents Hot Tears in Steel Castings. W. J. Phillips. (Foundry, 1940, vol. 68, July, pp. 27–28, 87–89). The author describes an investigation the object of which was to determine the factors leading to the formation of cracks which form in steel castings while the metal is still at a high temperature. Special test moulds were used so as to create a " hot spot " where the cracks would be likely to occur. The first possible cause examined was the influence of the hardness of the core ; a series of cores covering a wide range of hardness were used in the moulds, and it was found that variations in core hardness within the range employed in commercial practice had no influence on the occurrence of cracks. The effect of the pouring temperature was studied next and the results were found to be very erratic. It was, however, noticed that all the castings which showed cracks were poured with the last metal from the ladle from excessively hot heats. A microscopical examination was then made, and this established a definite relationship between the presence of hot tears and the shape of the inclusions present in the steel. In the author's opinion the tendency for hot tears to form in steel castings is definitely increased by the presence of inclusions of a certain type (micrographs of which are presented), which are associated with the amount of aluminium present and the manner in which it is added.

PRODUCTION OF STEEL

Basic-Brick Roof Construction. H. S. Robertson. (Proceedings of the Open-Hearth Conference of the American Institute of Mining and Metallurgical Engineers, 1940, pp. 44–50). The author describes and illustrates some details of the design of open-hearth furnace roofs using basic bricks, with special reference to the arrangements for permitting expansion. He also describes Lindemuth's checker design for all-basic furnaces, which has straight flues from top to bottom with no cross openings ; these are more easily blown and have given good service for more than 1000 heats without any replacements or other cleaning.

Proceedings of Twenty-Third Open-Hearth Conference. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Conference, Apr. 24–26, 1940). The Twenty-Third Open-Hearth Conference of the American Institute of Mining and Metallurgical Engineers was held at Pittsburgh and the proceedings were opened on April 24 with some introductory remarks by the General Chairman, L. F. Reinartz. The principal subjects dealt with were : (1) Refractories ; (2) furnace construction ; (3) acid open-hearth charging and melting, refining and deoxidation, operating and construction problems ; (4) joint problems of the blast-furnace and the open-hearth furnace ; (5) problems of steel quality ; and (6) general steelworks problems.

In the discussion on refractories many members related their experience with regard to reducing the number of inclusions in steel, improved nozzles, the use of olivine/chrome-ore mixtures and of rammed " Ramix " for furnace repairs, and the use of anti-piping compounds such as " Lapix," " Lunkerite," and " Therlumit." On the second subject of furnace construction, H. S. Robertson contributed a paper " Basic-Brick Roof Construction " (*see* preceding abstract) ; G. L. Dow described stud-tube furnace doors, and various members discussed attempts to stream-line an open-hearth furnace to facilitate the flow of the gases. The third subject was dealt with by the newly constituted Acid Open-Hearth Group in the form of an open discussion. A joint session of the Open-Hearth Steel and Blast-Furnace and Raw Materials Committees discussed the fourth subject. In this session the following papers were read : " Manufacture of Low-Silicon Pig Iron Using High Blast Temperatures " by C. F. Hoffman ; " Open-Hearth Operations on Low-Silicon Basic Iron " by E. A. Wheaton ; " Hot-Metal Requirements of Open-Hearth Operators Using High-

Scrap–Low-Metal Practice " by L. R. Berner ; and " Quality of Iron for Open-Hearth Use " by H. W. Johnson. (Abstracts of these papers will be found in the appropriate sections of this bulletin). The fifth subject was begun with a discussion on the use of compressed light scrap in steel furnaces, after which F. M. Washburn and W. O. Philbrook contributed a paper on " Theory and Practice of Slag Control in the Basic Open-Hearth Furnace " (see p. 11 A). This was followed by a general discussion on rapid methods of estimating the composition of open-hearth slag. K. L. Fetters then contributed some information and graphs on the proportion of the iron oxide in the slag to that in the metal, and the relation between this and the carbon and manganese contents. J. Chipman next produced data showing that the iron-oxide content of the metal is very much more closely related to the carbon content of the metal than it is to the iron-oxide content of the slag alone. Discussion then took place on the use of aluminium in small pigs, or as small shot, for killing steel, and opinion favoured adding the metal in a stream of small shot to the steel at the end of the furnace spout. The problems dealt with under the sixth and last heading included : (a) The cleaning of checkers during a furnace campaign ; (b) the relative merits of the Carbometer, the Carbanalyzer and the Leco carbon apparatus ; (c) soaking-pit practice ; (d) maintenance of tap-holes ; (e) the extent to which mill scale can be substituted for ore in charging when a high proportion of metal is charged ; and (f) the use of oxygen recorders to assist in controlling the air/gas ratio.

What Does Automatic Combustion Control Mean to the Open-Hearth Operator ? M. J. Boho. (Proceedings of the Open-Hearth Conference of the American Institute of Mining and Metallurgical Engineers, 1940, pp. 266–270). The author considers the benefits that can be derived from automatic control of (a) the furnace pressure, (b) the fuel input, (c) the fuel/air ratio, and (d) the reversal of the valves, in the working of an open-hearth furnace.

Hot-Metal Requirements of Open-Hearth Operators Using High-Scrap–Low-Metal Practice. L. R. Berner. (Proceedings of the Open-Hearth Conference of the American Institute of Mining and Metallurgical Engineers, 1940, pp. 160–162). The author gives reasons why a certain analysis of hot metal proved to be most suitable for producing steel in a basic open-hearth furnace operating with a high scrap/hot-metal ratio. The analysis in question was : silicon 0·95–1·05%, manganese 1·80–1·95%, sulphur 0·020% max., phosphorus 0·200% max., and copper 0·03% max.

Open-Hearth Operations on Low-Silicon Basic Iron. E. A. Wheaton. (Proceedings of the Open-Hearth Conference of the American Institute of Mining and Metallurgical Engineers, 1940, pp. 151–154). The author points out some of the advantages gained in the working of basic open-hearth furnaces by using hot metal containing only 0·60–0·90% of silicon as compared with

earlier practice when metal containing about 1·15% of silicon was used.

"Stakhanov" Methods of Rapid Open-Hearth Melting at the Stalin Kuznetskiy Works. V. Savostin. (Stal, 1939, No. 10–11, pp. 18–22). (In Russian). A considerable amount of data, presented in tabular and diagrammatic form, relating to the timing of the different operations, consumption of the raw materials, and the variations in metal and slag compositions during the course of a heat at the open-hearth furnaces at the Stalin Kuznetskiy Works are briefly discussed. It is concluded that the duration of a heat in a 190-ton furnace could be reduced to a maximum of 8 hr. The time taken for the different operations was as follows : patching, 15 min. ; charging, 1 hr. ; heating up, 1 hr. ; melting, 3 hr. ; addition of ore and finishing, 2 hr.

Manganese Losses in Open-Hearth Practice. (Iron and Coal Trades Review, 1940, vol. 141, Aug. 16, pp. 167–169 ; Aug. 23, pp. 188–189). An abridged English translation is presented of a paper by Bardenheuer and Henke on the prevention of the loss of manganese in the open-hearth process. This appeared originally in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 16, pp. 243–260. (*See* Journ. I. and S.I., 1940, No. I., p. 80 A).

HEAT TREATMENT

The Case-Hardening of Steel. E. Gregory. (Engineering Inspection, 1940, vol. 5, Summer Issue, pp. 3–15). After describing the theory and practice of the case-hardening of ordinary carbon steel, the author goes on to discuss the correct treatment for case-hardening free-cutting steels high in sulphur, the effect of changes in the manganese/sulphur ratio, the detrimental effect of a high phosphorus content on the hardening properties, and the treatment for hardening steels containing nickel and nickel plus chromium. In conclusion he deals with a number of common causes of failure and illustrates some specimens which had " peeled " or showed grinding cracks.

The Effect of the Carburised Layer on the Quenching of the Steel Core. V. I. Prosvirin. (Vestnik Metallopromyshlennosti, 1939, No. 10–11, pp. 106–107). (In Russian). The author carried out some experiments which showed that the hardness of the cores of cylindrical carbon-steel specimens carburised and quenched was greater than that of uncarburised quenched specimens. He attributes the effect to compressive stresses set up in the core of the carburised specimens.

New Heat-Treatment Plant at Commonwealth Steel Co., Ltd. (B.H.P. Review, 1940, vol. 17, Apr., pp. 8–9). **Heat Treatment in Australia.** (Iron and Coal Trades Review, 1940, vol. 141, Aug. 9, p. 141). A brief illustrated description is given of the new oil-fired and electric furnaces for the heat treatment of forgings and castings which have recently been added to the plant of the Commonwealth Steel Co., Ltd., Newcastle, New South Wales.

Distortion in the Heat Treating of Meehanite Metal. T. E. Eagan. (Heat Treating and Forging, 1940, vol. 26, May, pp. 225–229). The author discusses methods of preventing or reducing distortion in the heat treatment of Meehanite. The factors affecting distortion are the shape and dimensions of the piece, and the methods of heating and cooling. Abrupt changes of section and sharp corners are detrimental factors. In quenching, the heaviest section of the piece should enter the bath first, the piece or the quenching medium should be kept in motion, none of the medium should be allowed to be trapped in pockets or holes, and the piece should be removed when its temperature has fallen to 300–500° F. and then tempered immediately.

WELDING AND CUTTING

Atomic Hydrogen. R. M. Fenton and E. W. Dougherty. (Iron Age, 1940, vol. 146, July 18, pp. 40–42). The authors describe and illustrate the atomic-hydrogen welding equipment installed by the Otis Steel Co., Cleveland, Ohio, for welding together the ends of coils of strip as the hot strip leaves the 30-in. mill. They explain the principles of this method of welding and its advantages as applied to strip mills. The apparatus described is automatically put in action and stopped by a Thyratron valve control.

Comparison of Process Techniques for Welding of Cast Iron. R. J. Franklin. (Welding Engineer, 1940, vol. 25, Feb., pp. 30–33). The author describes different techniques which have been developed for the autogenous and electric welding of cast iron. He stresses the importance of careful preparation of the surfaces to be welded and explains why preheating is usually necessary.

New Method of Automatic Welding with a " Lying " Electrode. S. Z. Shterling. (Vestnik Metallopromyshlennosti, 1939, No. 10–11, pp. 81–87). (In Russian). In welding with a " resting " electrode, a coated electrode is placed along the V or gap to be welded. Current is supplied to one end of the electrode and an arc is struck between the other end and the work ; the arc continues to burn and move along the seam without further attention. Early experiments in this direction were, however, unsuccessful, owing to distortion of the electrode by the heat and its erratic behaviour. Work in Russia towards the end of 1938 led to the development of an eccentrically coated electrode for this method of welding, the thin side of the coating being placed downwards in contact with the metal to be welded, while the upper thicker side of the coating, which took longer to fuse, formed a protective " hood " over the arc. Satisfactory results were obtained in this way. In the experiments described by the author electrodes with an ordinary coating were used. After the electrode had been placed in the seam it was covered by a layer of paper, over which was placed a copper bar with a groove on the under side. The copper bar was held down by screw clamps. The tests were made on mild steel. A special coating free from organic material and consisting of 37·7% of titanium ore, 28·6% of manganese ore, 20·4% of ferro-manganese and 13·3% of feldspar, and made up with 26·5–28·5% of water-glass, was developed. A steady arc was obtained with this coating, and the finished welds had a high ductility.

MACHINING

Testing of Cutting Efficiency of Tools. A. J. Schroeder. (Metallurgia, 1940, vol. 22, July, pp. 95–97). The author describes the procedure which he recommends for making comparative tests of the cutting efficiency of high-speed tool steels, using a lathe for turning a forged and annealed steel shaft 10–15 in. in dia.

A New View of High-Speed Steels. R. Kikuchi. (Tetsu to Hagane, 1940, vol. 26, May 25, pp. 361–366). (In Japanese). The author has investigated the cutting efficiency of high-speed steels high in cobalt. He comes to the conclusion that the most economical composition consists of about 15% of cobalt and about 20% of tungsten, and that the carbon content should be decreased with increasing cobalt content.

Machining of Metals during Heating by Induction with High-Frequency Current. B. M. Askinazi and G. I. Babat. (Vestnik Metallopromyshlennosti, 1939, No. 10–11, pp. 74–80). (In Russian). The authors carried out some preliminary experiments on the rough-turning of steel heated in a high-frequency induction furnace to temperatures of 800–900° C. A high-frequency generator and condenser were used to supply the current through a special co-axial feeder to a water-cooled induction heating coil which was mounted on the lathe bed. Some data are given regarding the temperatures and depths of heating which can be obtained with different high-frequency current strengths. Experiments, in which the maximum cutting speed and feed of the lathe were employed, and in which the cutting depth was increased until the lathe was stopped, showed that, with correct tool design, machining at a temperature of 900° C. increased the output very considerably. The indications were that in high-temperature machining the best results are obtained with high cutting speeds of 80–100 m. per min. A very smooth surface could be obtained and quench-hardening effects were observed on the surface of the material.

Structural Changes in the Surface Layers of Quenched Steel under the Influence of Grinding. L. V. Al'tshuler and M. P. Speranskayay. (Vestnik Metallopromyshlennosti, 1940, No. 1, pp. 15–21). (In Russian). Earlier studies of the surface finish, structure and wear-resistance of the ground steel surfaces which are so important in the manufacture of measuring instruments are briefly referred to. X-ray investigations by the authors on 1·5% chromium tool steel ground either after quenching or after quenching and artificial ageing at 150° C. for 3 hr., showed that in both cases grinding had at least

the effect, judging by the structure produced, of a high-temperature tempering on the surface layers of the specimens. Coarse-grinding of quenched steel produced an austenitic structure on the outer sur- face layer, below which successive layers showed gradually diminish- ing temper effects, the layers merging into the original quenched steel with a tetragonal martensitic structure. The amount of austenite found increased with increasing quenching temperature of the steel being ground. The authors conclude that the grinding of unquenched steel does not lead to the formation of austenite. The above transformations cause stresses to be set up in a surface layer approximately 0·1 mm. thick. These stresses may lead to grinding cracks, and they also account for the previously observed reduced wear-resistance of the 0·1-mm. surface layer of ground-quenched steel. It is estimated that grinding causes localised heating to 1000° C. for 5×10^{-5} sec. This very rapid heating explains the above structural changes observed in the surface layers of ground quenched and unquenched steels.

The Manufacture of Rolls-Royce Aero-Engines. (Machinery, 1940, vol. 55, Feb. 15, pp. 525–544 : Canadian Metals and Metal- lurgical Industries, 1940, vol. 3, June, pp. 144–146, 151). A detailed and illustrated description of the machining and heat-treatment processes at the Rolls-Royce works, where the accelerated production of the Merlin engine is in progress, is presented.

Finishing the Surface of Steel Mill Rolls. D. C. Turnbull. (Blast Furnace and Steel Plant, 1940, vol. 28, May, pp. 495–498). The author gives some details of the design and performance of a machine for finishing the surface of rolling-mill rolls. It is known as the " Wheelabrator," and in it there is a revolving wheel $19\frac{1}{2}$ in. in dia. with a $2\frac{1}{2}$-in. face which is capable of throwing 300 lb. of metallic abrasive material per min. against the roll. The roll is mounted and revolved at up to 10 r.p.m. and caused to move lengthwise through the stream of abrasive. The surfaces produced by abrasives of different hardness are illustrated by a series of micrographs.

CLEANING AND PICKLING OF METALS

Flame Cleaning, Dehydrating and Descaling. J. G. Magrath. (International Acetylene Association : Heat Treating and Forging, 1940, vol. 26, May, pp. 217–221, 235). After giving particulars of the composition of scale on rolled and forged steel, the author describes the theory and practice of dehydrating and descaling with the oxy-acetylene torch.

Flame Scarfing Billets. J. Heffley. (Steel, 1940, vol. 107, July 15, pp. 54–55, 76). The author gives an account of the equipment and technique employed at the Buffalo plant of the Republic Steel Corporation for conditioning the surface of billets with torches burning a mixture of natural gas and coke-oven gas at 12 lb. per sq. in. with a high-pressure supply of oxygen as the cutting gas. In 1937, 9% of the billets were " flame-scarfed " in this way, and in 1939 the proportion had risen to 75%.

Billet Grinding. A. O. Rousseau. (Iron Age, 1940, vol. 145, June 20, pp. 45–47). The author discusses the factors affecting the efficiency and economy of grinding in the dressing of high-chromium and chromium-nickel steel billets. He deals in particular with the effects of increasing the speed of the grinding wheel and the pressure with which it is applied to the surface. His general conclusions are : (1) The rates of grinding and of wheel wear are proportional to the surface speed of the wheel ; (2) the wheel wear per unit of work ground remains constant regardless of wheel speed ; (3) increasing the pressure increases both rate of cut and rate of wheel wear.

Electropolishing. S. Tour. (Metal Finishing, 1940, vol. 38, June, pp. 308–312). The author reviews the patents and literature on electrolytic processes of polishing metal surfaces and describes the Blaut-Lang process in detail. (*See* p. 113 A).

Loose Abrasive Finishing. H. W. Faint. (Monthly Review of the American Electroplaters' Society, 1940, vol. 27, June, pp. 449–450). The author describes the technique for obtaining a smooth, lustrous surface on steel and stainless-steel articles by polishing with muslin wheels about 14 in. in dia. to which a loose abrasive mixed with oil or water is applied.

An Optical Smoothness-Meter for Evaluating the Surface Finish of Metals. J. Guild. (Journal of Scientific Instruments, 1940, vol. 17, July, pp. 178–182). The author describes an optical instrument which was developed for testing the quality of finish of flat, or approximately flat, metal surfaces. The design of the instrument is based on the principle that a beam of light incident

on a reflecting surface is reflected in a manner depending on the fine-scale character of the surface. For surfaces intermediate between perfectly smooth and perfectly rough, *i.e.*, completely matt, the reflected light is diffused in all directions, but is most strongly concentrated in and near the direction of specular reflection. The fraction of the total reflected light which is comprised within a small cone the axis of which is in this direction provides a measurable property which increases with the smoothness of the surface. The instrument comprises a source of light, an integrating sphere, suitable lenses and a photo-electric cell of the rectifier type connected to a galvanometer.

A Revolution in Pickling Methods. A. McLeod. (Sheet Metal Industries, 1940, vol. 14, July, pp. 715–721). The author describes the pickling process recently introduced by de Lattre and some plants in Belgium where the process is being successfully used. He discusses the disadvantages of regenerating liquors produced in hydrochloric-acid pickling, which include the production of excess ferrous sulphate and of dense fumes of hydrochloric acid, and explains that these disadvantages are overcome in the de Lattre process by using sulphuric acid and ferrous chloride with an inhibitor. The most favourable conditions are produced when the pickling liquor contains per litre : 1 g.-mol. of ferrous sulphate, 1–2 g.-mol. of hydrochloric acid and 1 g.-mol. of sulphuric acid. This solution is maintained at a constant temperature of 50–55° C. by steam coils, and the ratio of the two acids is maintained during the whole pickling operation by appropriate additions of both acids and the inhibitor which consists of gelatin peptonised by hydrochloric acid. Pickling is carried on until the total ferrous-sulphate concentration reaches 326–394 g. per litre, when the solution is passed to the recovery plant. The recovery or regenerating plant is of particular interest, as it presents a complete solution to the problem of the disposal of waste pickling liquors. The spent liquor is first led into a preliminary settling-tank in which unwanted sludge is separated out. From here the solution is syphoned into crystallising tanks, the cooling system for which consists of multiple coils of lead pipes. The ferrous-sulphate crystals pass by gravity into a centrifugal drier and the liquid drawn off returns to a reservoir tank for redistribution in the pickling shop. At one Belgian works seven lots of liquor were regenerated per 8-hr. shift and 8·4 tons of ferrous sulphate were recovered per 24-hr. day ; before the present war these crystals were sold in Holland at 30*s*. per ton. The author outlines the I.G. Farbenindustrie process of manufacturing sulphuric acid from ferrous-sulphate crystals, and concludes by emphasising the advantages of using the de Lattre process for pickling steel strip.

COATING OF METALS

Metal Spraying by the Wire Process—Considered as a Finish. W. E. Ballard. (Sheet Metal Industries, 1940, vol. 14, July, pp. 747–750). After a brief description of the process of metal spraying and the metal-spraying pistol, the author discusses the effects of different methods of surface preparation on the finish of a sprayed metal coating. In conclusion he refers to the decorative effect that can be obtained by spraying through sheet-metal stencils and by applying metals of different colours.

Metal-Spray Protection of Refinery Equipment. D. R. Johnson and E. K. Dewey, jun. (Welding Journal, 1940, vol. 19, June, pp. 397–401). The authors describe numerous examples of the use of metal-spraying to prevent the corrosion of the interior surfaces of reaction chambers, bubble towers, storage tanks and other refinery equipment. The metals used include aluminium, brass and stainless steel. Some unsuccessful instances are also mentioned ; these were usually accounted for by the fact that the coating was applied under bad atmospheric conditions.

The Best Fluxing Technique for Hot Dip Galvanizing. W. G. Imhoff. (Wire and Wire Products, 1940, vol. 15, June, pp. 312–317). The author describes the theory and practice of two methods of fluxing in galvanising. The earlier method consisted of pickling in sulphuric acid, then dipping in hydrochloric acid, allowing to dry and then passing the sheet through a layer of molten sal-ammoniac into the molten zinc. In the more recent and more economical method a slightly acid solution of zinc-ammonium chloride is used instead of the hydrochloric-acid bath.

Hot Tinning of Individual Ferrous Components. J. G. Marll. (Metal Treatment, 1940, vol. 6, Summer Issue, pp. 79–84, 94). The author discusses the following items which are of importance in the design and operation of a modern plant for the tinning of individual ferrous components : (1) The type of material from which the component is produced ; (2) the machining or press operations and the heat treatment to which the article has been subjected ; (3) the condition of the surface ; (4) cleaning by degreasing and pickling ; (5) fluxing ; (6) the technique of tinning ; (7) finishing operations ; and (8) plant considerations.

The Relation of Defects in Enamel Coatings to Hydrogen in Steel. C. A. Zapffe and C. E. Sims. (Journal of the American Ceramic Society, 1940, vol. 23, July, pp. 187–215). The authors present an account of an investigation of the relationship between

the presence of hydrogen in steel, the difficulties which arise during enamelling and defects which are subsequently observed in a finished enamelled article. They commence with an examination of the source of the hydrogen present in finished steel, and then describe numerous experiments in which specimens of steel containing hydrogen and inclusions artificially introduced were enamelled and fired, and their behaviour was studied. Their general conclusions are as follows : (1) Hydrogen dissolved atomically in steel may cause enamelling defects, because diffusion is exceedingly slow at ordinary temperatures and equilibrium may not be reached unless the steel is carefully treated ; (2) molecular hydrogen occluded in cavities will be released only when the steel is brought to enamel-firing temperatures. The initial release is indicated by the formation of bubbles in the soft enamel, but as the temperature rises the solubility of hydrogen in steel increases so that the hydrogen redissolves, which causes the bubbles and blisters to subside. Upon cooling, the hydrogen again comes out of solution, part of it seeking the cavities from which it originated and part of it forming precipitates at the metal-enamel interface causing scaling defects ; (3) hydrogen retained in inclusions or impurities in the steel may react with the impurity to form compounds of various degrees of stability, and gases will be evolved from those which are unstable at the temperature of firing ; (4) the chemical bond between carbon and hydrogen is very strong and large amounts of hydrogen combine with carbide structures to form what is perhaps a quasi-methane structure. These iron-hydrocarbon structures decompose during firing to liberate hydrogen, thus causing a boiling action at the enamel surface. This has sometimes been wrongly identified as a carbon-oxygen reaction ; and (5) " delayed fish-scaling " is the result of a sustained slow effusion. A bibliography of 219 references is appended.

Surface Treatment of Steel Prior to Painting. R. E. Pollard and W. C. Porter. (United States National Bureau of Standards, Report BMS 44, Apr., 1940 : Iron Age, 1940, vol. 146, July 11, pp. 48–49). The authors report on tests made to determine the effects of different surface-treatment processes on the life and corrosion resistance of subsequent paint coatings on plain and galvanised steel sheets. The finished specimens were subjected to accelerated weathering, salt-spray and condensation-corrosion tests. It was found that a hot-dip phosphate solution treatment was of outstanding merit in improving the protective value of paints for both plain and galvanised steel. A phosphate cold wash for galvanised steel and two phosphate-chromate washes for plain steel were also found to be very effective.

PROPERTIES AND TESTS

Graphical Analysis of Thermal Stresses. D. White. (Welding Journal, 1940, vol. 19, June, pp. 231-S–238-S). The author describes and explains a method of determining the amount of stress and distortion arising in a steel part as a result of local heating. The method is based on the construction of temperature-distribution diagrams for sections of the part and calculations of the strains for different areas from the expansion curves for steel. In the example given, the author shows how the method was applied in order to improve the design of a large brake drum, but it can also be used to calculate stresses and strains caused by welding.

Study of Lattice Distortion in Plastically Deformed Alpha Iron. N. P. Goss. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1218 : Metals Technology, 1940, vol. 7, Aug.). The author describes a new X-ray technique which has been developed for the study of plastically deformed metals, and its application for the study of the changes in the properties of α-iron which has been subjected to cold-work. With this technique the K_α doublets can be sharply resolved by using an almost parallel beam of X-rays diffracted by the surface at the proper angle of incidence. Using the apparatus and technique described, the author's observations led to the following conclusions : (1) Plastic deformation does not distort the space lattice of α-iron but splits up the grains into smaller particles ; (2) the decrease in density that accompanies cold-working can be explained by the increase in the internal surface due to new orientations created within the grain by grain fragmentation ; (3) a single crystal has maximum density and all fine-grained annealed aggregates and fragments created by plastic deformation have a slightly lower density ; (4) the theory of Jeffries and Archer that the hardening of a metal by cold-working is due to mechanical refinement of the grains into smaller ones differing in orientation from the parent grain is supported by evidence obtained by the new technique ; (5) there is a limit to the degree of fragmentation of the grains caused by cold-working, and this limit appears to be particles about 10^{-5} cm. in magnitude ; and (6) the X-ray method described is capable of determining with great accuracy the average particle size for any given plastic deformation.

The Effect of Crystalline Structure on the Properties of Metals. W. Boas. (Journal of the Institution of Engineers, Australia, 1940, vol. 12, May, pp. 147–152). The author explains the fundamentals

of the crystalline structure of metals. In Part I. he discusses the properties of single crystals. In Part II. he deals with the arrangement of crystallites in the aggregate and explains some systems of preferred orientation and the phenomenon of slip. In Part III. he applies data on the properties of single crystals presented in Part I. to the calculation of Young's modulus, electrical resistivities and coefficients of expansion of polycrystalline materials. Finally, in Part IV. he gives some examples of the anisotropic behaviour of polycrystalline materials.

Turbine-Blade Fatigue Testing. R. P. Kroon. (Mechanical Engineering, 1940, vol. 62, July, pp. 531–535). The author discusses methods of carrying out fatigue tests on turbine blades and describes some of the special machines which have been devised for making the tests at room and at high temperatures on either one blade or a whole segment of blades.

The Fatigue and Impact Strengths of Cast Iron. J. W. Donaldson. (Foundry Trade Journal, 1940, vol. 63, Aug. 8, pp. 91–93, 96). The author refers to the review he made in 1936 of researches concerning the fatigue and impact strengths of cast iron (*see* Journ. I. and S.I., 1936, No. II., p. 227 A), and he brings this up to date by reviewing more recent researches of German, American and British investigators.

Hardness in the Stressed State. D. M. Zagorodskikh. (Vestnik Metallopromyshlennosti, 1939, No. 10–11, pp. 54–59). (In Russian). The author investigated the hardness of steel under different conditions of stress. To do this he carried out Shore and Rockwell hardness tests on normalised specimens of two mild steels while they were being subjected to torsion tests. It was found that under torsional stress the hardness values as measured by the Rockwell and Shore methods did not change in the same manner, the former remaining unchanged in the range of elastic deformation. At the yield point there was a drop in the Rockwell hardness of 7–17%. In one of the steels there was an increase in the Rockwell hardness after the yield point had been passed, whilst the other specimen did not show this. The Rockwell hardness of all the test-pieces was increased by fracturing. The Shore hardness increased at the yield point and increased continuously in the elastic-deformation range. In bend tests the hardness remained unchanged, whilst in the elastic range a progressive drop in hardness set in with plastic deformation.

Precipitation-Hardening of a Complex Copper Steel. J. W. Halley. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1213 : Metals Technology, 1940, vol. 7, Aug.). The author reports on an investigation of the precipitation-hardening of a low-alloy steel containing copper, nickel and phosphorus as alloying elements. Two steels, differing primarily in silicon content, were used. These steels contained : Carbon 0·09% and 0·11%, manganese 0·49% and 0·66%, phosphorus 0·123% and 0·121%, sulphur 0·032% and 0·025%, silicon 0·188% and 0·020%,

copper 0·99% and 1·16%, and nickel 0·49% and 0·57%, respectively. He found that the change in the silicon content had a marked effect on the rate of precipitation-hardening, for in the steel containing 0·020% of silicon this rate was more than double that for the steel containing 0·188% of silicon.   Tensile tests proved that the physical properties of a precipitation-hardened low-silicon steel were equal to those of many quenched and tempered steels.

Magnetic Method of Checking the Heat-Treatment of Steel Wire. I. M. Korotin, I. Ya. Levshuk and V. I. Nikolin.   (Vestnik Metallopromyshlennosti, 1939, No. 10–11, pp. 122–127).   (In Russian). In steel wire for springs the presence of martensite and appreciable amounts of pearlite and troostite is undesirable.   The wire should possess a primary sorbitic structure.   In the present paper the authors describe the development of an apparatus, based on magnetic-induction principles, in which the magnetic permeabilities of the specimen and of a standard wire at definite field strengths are compared by the differential method, with the object of providing a means of checking the suitability of the structure of heat-treated wire.   Experiments on wires subjected to different forms of heat treatment showed that the apparatus could differentiate between correctly and incorrectly heat-treated wire.

Anti-Friction Cast Iron as a Substitute for Bronze.   J. I. Feygin. (Vestnik Metallopromyshlennosti, 1939, No. 10–11, pp. 39–43). (In Russian).   A brief summary is presented of the relevant details regarding the structure, properties, production, applications and behaviour in service of a low-alloy anti-friction cast iron.   Two compositions were developed, both of which were pearlitic irons produced in a cupola, one with a medium amount and the other with a large amount of lamellar graphite.   One contained total carbon 3·2–3·6%, silicon 2·2–2·4%, manganese 0·6–0·9%, nickel 0·3–0·4%, copper 0·2–0·3% and aluminium 0·2–0·35% ; the other had the same composition except that no copper and aluminium were present.   The structure consisted of a ground-mass of pearlite, ferrite being either absent or present up to 15%, and carbides of the cementite and other types being absent.   The phosphide eutectic was present in the form of fine inclusions.   The irons had a hardness of 160–229 Brinell.   The pearlitic matrix in cast irons with these compositions could be obtained in castings within a wide range of sections.   The composition of the cupola charge and the melting practice for producing these irons are specified ; the iron should be tapped at 1380–1420° C. and cast in green sand.   The coefficient of friction of these irons is about the same as that of bronze.

Metallurgical Aspects of Brake Drums for Heavy Duty Service. V. A. Crosby and G. A. Timmons.   (Foundry, 1940, vol. 68, July, pp. 32–34, 83–84).   The authors consider the essential properties of a cast iron which is to be used for the manufacture of brake drums for motor cars and lorries.   They explain the metallurgical changes which take place in the surface material of the drum when it is

rapidly heated by friction with the brake shoe and rapidly cooled by the mass of metal when the brake is released. They also present the results of tensile tests at 70°, 700°, 800°, 842°, 932° and 1000° F., on some grey cast irons and other cast irons alloyed with small additions of chromium, nickel and molybdenum, separately and in combination, and discuss which of these irons are suitable for brake drums.

Carbon Steel. W. Ashcroft. (Metallurgia, 1940, vol. 22, July, pp. 85–86, 100). The author points out that the advance in know-ledge resulting from work on alloy steels has reacted upon the technology of carbon steels, and has led to the discovery of the fact that properly treated carbon steels are comparable with some of the more expensive alloy steels in many applications. He discusses the improved methods of controlling the steelmaking and heat-treat-ment processes which have widened the field of application of carbon steel.

Effects of Low-Temperature Heat Treatment on Elastic Properties of Cold-Rolled Austenitic Stainless Steels. R. Franks and W. O. Binder. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1183 : Metals Technology, 1940, vol. 7, Aug.). The authors describe a number of tests the object of which was to ascertain the effect of annealing at different temperatures and for different lengths of time on the elastic properties of bars of 18/8 stainless steel which had previously been subjected to cold-work. After treatment for different periods of time at 400–600° C. the steels became subject to intergranular corrosion, and, whilst some improve-ment in the elastic properties was noted, the results were not always consistent. When the annealing temperature was about 300° C., the results were better, but were still not satisfactory. Annealing at 200° C. considerably improved the elastic properties, but the time factor was very important, for there was practically no improvement when the heating period was less than 8 hr. With 16 hr. heating at this temperature a decided improvement in the elastic properties took place and experiments with extended heating periods up to 168 hr. showed that holding for longer than 72 hr. produced no further improvement. A faint yellowish coating develops during the heat-ing period and this can be readily removed by dipping in hot nitric acid solution. The properties of 18/8 stainless steels containing either niobium or molybdenum are also improved by this annealing treatment. The authors' general conclusion from the data obtained is that annealing at 200° C. for the period mentioned above increases the fatigue resistance and improves the toughness somewhat without rendering the steels subject to intergranular corrosion or reducing their resistance to general corrosion.

Effect of Low-Temperature Annealing on Properties of Cold-Drawn Cr–V Steel Wires. M. Kawasaki. (Tetsu to Hagane, 1940, vol. 26, Apr. 25, pp. 281–287). (In Japanese). The author reports on an investigation of the effect of low-temperature annealing on the

mechanical properties of cold-drawn chromium-vanadium steel wire, a steel used for making exhaust-valve springs for aircraft engines. The steel used contained about 0.5% of carbon, 0.5% of manganese, 1% of chromium and 0.2% of vanadium. The general effect of the cold-drawing was to increase the hardness and tensile strength and to decrease the plasticity. The hardness and tensile strength of specimens which had been cold-reduced 19.6% and 47.8% respectively were brought to maximum values by annealing at $300°$ C.

British Standard Specification for Carbon Steel Castings for Ships and for Marine Engine and General Engineering Purposes. (British Standards Institution, No. 592, revised 1940). This British Standard Specification replaces the earlier specifications 592–1935, 30–1907 and 5028–1924 which were for steel castings for general engineering purposes, for marine purposes and for automobiles respectively. The new specification covers the following grades of castings, *viz.*, those having a tensile breaking stress of 28–35 tons per sq. in., 35–40 tons per sq. in., and a non-test grade.

The Influence of Some Special Elements Upon the Strain-Ageing and Yield-Point Characteristics of Low-Carbon Steels. C. A. Edwards, D. L. Phillips and H. N. Jones. (Iron and Steel Institute, 1940, this Journal, Section I.). The influence of carbon, aluminium, copper, nickel, molybdenum, manganese, chromium, vanadium, niobium and titanium upon the strain-age-hardening properties of low-carbon steels was studied. It was found that these elements can be divided into two main groups, *viz.*, those which show little or no tendency to combine with the carbon present in steel (aluminium, copper and nickel) and those which show definite tendencies to form carbides (molybdenum, manganese, chromium, vanadium, niobium and titanium). The former increase and the latter diminish the extent of strain-age-hardening of low-carbon steels.

It would seem that when sufficient of one of the elements of the second group is added to combine with all the carbon present the material does not strain-age-harden. The amount of alloying element required to bring this about varies with its chemical affinity for carbon, and the percentage is relatively small in the case of niobium and titanium. Thus it seems evident that one form of strain-age-hardening can be definitely traced to the presence of carbon and the condition in which it exists in the steel. It was also found that as the capacity for strain-age-hardening is diminished by increasing quantities of specially added elements, the intensity of the yield point diminishes, and no yield point is revealed on a stress-strain diagram when sufficient alloying element is present to prevent strain-age-hardening. Tentative explanations for the cause of the yield point are put forward.

METALLOGRAPHY AND CONSTITUTION

The Reduction of Secondary Radiation and of Excessive Radiographic Contrast by Filtration. H. E. Seemann. (American Society for Testing Materials, June, 1940, Preprint 110). The problem of making a satisfactory radiograph of small or irregular objects is resolved into preventing over-exposure in thin or open regions, and, at the same time, obtaining a satisfactory record of thick parts. Berthold has shown that, when a lead filter is used between the object and the film, an additional filter of tin improves the image obtained. In the present paper the author describes experiments which show that still further improvement in the quality of the radiographs can be obtained by placing the filter as near the X-ray tube as possible.

Sorby's Pioneering Work on the Microstructure of Rocks and Metals. J. H. G. Monypenny. (Metal Progress, 1940, vol. 38, July, pp. 45–48, 86, 106). The author presents a brief historical sketch of Sorby's early work on the examination of rocks and metals under the microscope.

Determination of the Austenite Grain Size in Low-Carbon Steel. S. A. El'got and Z. A. Smirnova. (Zavodskaya Laboratoriya, 1940, No. 3, pp. 335–339). (In Russian). The authors have compared three methods of determining the grain size of 2·5-mm. hot-rolled steel sheet using specimens prepared from heats of low-carbon killed and rimming steel (carbon 0·05–0·07%). The methods used were the McQuaid-Ehn cementation method, etching at high temperature, and oxidation at high temperature. They found that the cementation method did not give definite results. With sheet of rimming steel, segregation led to the formation of two layers, an outer layer of large grains of austenite sensitive to overheating, and an inner layer of finer austenite grains less susceptible to overheating. With killed steel the austenite grains were of uniform size throughout.

The Grain Size of High-Speed Steel. Z. N. Arkhangel'skaya. (Vestnik Metallopromyshlennosti, 1939, No. 10–11, pp. 60–63). (In Russian). In view of the inconsistency of the structure and hardness of high-speed steel from different heats but of the same composition (carbon 0·68%, tungsten 18%, chromium 3·8% and vanadium 0·7%) after quenching from 1300° C. and repeated tempering at 580° C., the author carried out an investigation of (a) the effect of preliminary heat treatment on the grain growth observed after subsequent quenching and tempering, (b) the effect of the holding time at 1300° C. on the grain growth of the austenite, and (c) the relation between the grain size of the austenite and the

wear resistance of the tools. Preliminary heating and quenching was found to increase the grain size and hardness obtainable after subsequent quenching and tempering, whilst preliminary annealing at 860° C. resulted in a finer grain and lower hardness after final heat treatment. The cutting properties of the tool steel were improved by applying the heat treatment which increased the grain size.

Rate of Diffusion of Carbon in Austenite in Plain Carbon, in Nickel and in Manganese Steels. C. Wells and R. F. Mehl. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1180 : Metals Technology, 1940, vol. 7, Aug.). The authors report on an investigation the objects of which were : (1) To determine, more accurately than hitherto, the diffusion co-efficients of carbon in austenite over wide ranges of temperature and concentration ; (2) to study the influence of grain size and impurities on the diffusion coefficient ; and (3) to study the effect of manganese and nickel on the rate of diffusion of carbon in the austenite of manganese and nickel steels respectively. The procedure adopted consisted of welding together the ends of pairs of cylindrical specimens, one being high and the other low in carbon, using Armco iron, unalloyed steel and steels alloyed with nickel and manganese. After welding, the specimens were annealed in order to diffuse the carbon across the welded interface, and carbon concentration-penetration curves were drawn from data obtained by the analysis of cuttings taken at increasing distances from the weld. The authors' main conclusions are : (1) The rate of diffusion increases with increasing carbon concentration, the increase in the rate being approximately 80% with an increase of carbon content from 0·1% to 1·0% ; (2) the increase in the diffusion rate appears to be independent of the temperature in the range studied, which was 750–1250° C. ; (3) in the grain-size range of − 3 to + 8 by the American Society for Testing Materials scale, the rate of diffusion does not change ; (4) the diffusion rate does not vary with different amounts of impurities ordinarily present in commercial steels ; and (5) large additions of manganese and nickel, such as 16–20%, increase the rate of diffusion, whilst the amounts of these elements ordinarily present in steels for case-hardening have no appreciable effects on the diffusion rate.

Crystallography of Austenite Decomposition. A. B. Greninger and A. R. Troiano. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1212 : Metals Technology, 1940, vol. 7, Aug.). The authors refer to recent studies of the martensite transformation in non-ferrous alloy systems which have established the irrational orientation habit as characteristic of the martensite type of reaction and which led them to undertake a thorough study of the crystallography of the formation of martensite in steel. The results of this study, extended to include both cementite and some of the products of the decomposition of austenite at constant temperatures, are reported in the present paper. Plain carbon

steels with carbon contents in the range 0·35–1·78% and nickel steels containing 11·5% and 32·5% of nickel were used in the investigation. The authors arrived at the following conclusions : (1) In none of the alloys studied does a martensite plate form on a plane of austenite with low indices ; (2) in 0·35% carbon steel the martensite crystals are needle-shaped and these crystals form in a plate-like array delineating the octahedral planes of austenite ; (3) the orientation of iron-carbon martensite changes abruptly at a carbon content of about 1·4% ; above this percentage it is complex ; (4) in steel of near-eutectoid composition, the martensite crystals are lath-shaped and the long dimension of the lath is parallel to $[110]_\gamma$; (5) the subnormal axial ratios for martensite reported by previous investigators are readily explained without assuming a direct dependence of axial ratio upon cooling velocity ; (6) the long straight direction of the cementite plates formed at Ar′ is approximately parallel to [134] of austenite ; (7) the orientation of the plate-like products of austempering treatment varies with temperature, and in none of the cases studied was it the same as that of martensite ; and (8) for 1·78% carbon steel at 300° C., and for 1·4% carbon steel at 350° C., the structure produced by austempering is definitely nodular, and in this connection the authors suggest that the products of austempering are formed as aggregates, not as single-phase particles. (*Note :* The special form of heat treatment known as " austempering " was described by Payson and Hodapp, *see* Journ. I. and S.I., 1939, No. II., p. 94 A).

Note on the Effect of Pressure on the Curie Point of Iron-Nickel Alloys. J. C. Slater. (Physical Review, 1940, vol. 58, July, pp. 54–56). By applying Clapeyron's equation, an estimate is made of the raising of the Curie point of nickel by pressure. For iron-nickel alloys the rise of the Curie point with pressure would become less as more iron is added, becoming zero with something like 70% of nickel, and for alloys containing more iron it would decrease with pressure. The author therefore considers it unlikely that the pressures existing in the iron-nickel core of the earth would raise the Curie point sufficiently to make this core ferro-magnetic at the temperatures existing inside the earth.

The Equilibrium Diagram of Fe–Al–Si System. S. Takeda and K. Mutuzaki. (Tetsu to Hagane, 1940, vol. 26, May 25, pp. 335–361.) (In Japanese). The authors report on their investigation, by microscopic, thermal, X-ray, magnetic and dilatometric methods, of the iron-aluminium-silicon system, from the results of which they construct the equilibrium diagram for the whole system.

The Brittle Phase in High Chromium Steels. Part II. J. H. G. Monypenny. (Metallurgia, 1940, vol. 22, July, pp. 87–93). The author concludes his review of the literature concerning the brittle and non-magnetic constituent of certain high-chromium alloys (*see* p. 72 A). In this part he pays particular attention to the iron-chromium-manganese alloys.

CORROSION OF IRON AND STEEL

Corrosion of Steels by Molten Nitrates. P. Lloyd and E. A. C. Chamberlain. (Iron and Steel Institute, 1940, this Journal, Section I.). The corrosion of steel containers by molten alkali nitrates is important in the heat treatment of aluminium alloys in salt baths. The process was investigated on a laboratory scale with special reference to the effects of temperature, method of heat application and impurity in the salt ; the influence of the material forming the pot was also examined. It was found that, although the corrosion rate increases rapidly with temperature, local over-heating of the container does not necessarily lead to accelerated corrosion at that point. The scaling rate was found to be a function of the composition of the steel. Alkali chlorides, present as impurities in most commercial salts, were found to stimulate corrosion. The equilibrium between the alkali nitrates and nitrites was also investigated.

The Corrosion-Resistance of Heat-Treatment Pots. V. I. Prosvirin and G. I. Alekseev. (Vestnik Metallopromyshlennosti, 1939, No. 10–11, pp. 108–109). (In Russian). The authors report on some tests on various metals and alloys the object of which was to find the best material to resist the attack of molten salts used for salt-bath carburising. Specimens of stainless steels, alloy steels, Ni-chrome, nickel and iron were tested in molten barium chloride at 1200° C. The loss-in-weight determinations showed that nickel and Ni-chrome offered the best resistance ; next came the high-nickel alloy steels, in particular steel *E YaZS* containing 0·30–0·40% of carbon, 2·3–2·9% of silicon, 0·40–0·70% of manganese, 0·020% of sulphur, 0·030% of phosphorus, 1·6–2·0% of chromium and 23–27% of nickel.

Corrosion and Tuberculation. H. A. Knudsen. (Journal of the American Water Works Association, 1940, vol. 32, Mar., pp. 387–392). The author discusses briefly the causes of corrosion and tuberculation on the inside of water pipes. He considers the conditions favouring electrolysis and the effects of dissolved oxygen and carbon dioxide. In explaining the formation of tubercles, he agrees with the generally accepted theory that these are formed by iron-consuming or iron-depositing bacteria such as *Crenothrix*. Once these bacteria gain a foothold on the pipe surface the tubercle deposit grows from iron assimilated and subsequently eliminated by the bacteria as ferrous hydroxide in a sheath surrounding them ; this sheath is subsequently oxidised to ferric hydroxide by oxygen dissolved in the water.

BOOK NOTICE

JEVONS, J. DUDLEY. "*The Metallurgy of Deep Drawing and Pressing.*" With a Foreword by H. W. Swift. 8vo, pp. xv + 699. Illustrated. London, 1940 : Chapman and Hall, Ltd. (Price £2 10s.).

The author has dedicated this book to " all craftsmen, students and intelligent industrialists," and it is true to say that none of these can fail to benefit by a most careful study of its contents. The dedication makes it clear that, unlike the majority of metallurgical works, it was not intended entirely or even primarily for metallurgists. That would have narrowed its scope and limited its usefulness. In catering for the wider group of readers the author has done the pressing industry a much greater service and at the same time has not sacrificed the interest of the metallurgical reader.

A less ambitious author would have been content either to treat the entire subject in a more general manner or to limit the scope of his work to a specialised section. Dr. Jevons, however, has been satisfied with nothing less than painting the whole of this huge canvas in detail, and only his very wide practical and theoretical knowledge of the subject has made this possible. The enthusiasm of the author in his subject and his very considerable literary skill and clarity of expression provide a constant stimulation of the interest of the reader.

The general arrangement of the book is excellent. Very logically, the author insists that for a proper understanding of the difficulties encountered in the press shop it is necessary to have at least an elementary knowledge of the methods by which sheet metal is made. The first chapter of the book deals with the production of brass sheet, and covers the melting, casting, rolling, heat-treatment and finishing processes ; the properties of the grades of brass sheet normally used for pressing are also described. The second chapter treats in a similar manner the manufacture of steel and its conversion into sheet possessing the properties necessary for cold-pressing. The latest improvements in rolling and heat-treatment technique are described in detail and an account is given of the various grades of sheet.

Then comes what is probably the most important section of the book—five chapters dealing with defects in sheet metal and the difficulties experienced during pressing and in the final product. These are treated generally and then in detail under the headings brass and steel. Here again a logical arrangement is followed, the first section dealing with those defects and difficulties attributable to the metal used, then with those resulting from the treatment accorded to the metal under the press, and finally with those which are attributable to other causes. The defects peculiar to brass and to steel are dealt with in separate chapters, while the more important troubles, such as season cracking in brass and stretcher-strain markings in steel, are given individual attention. Metals other than brass and steel which have been left out of the picture until this point in the book is reached are now dealt with in the next fifty-eight pages. These include

aluminium and its alloys, magnesium alloys, copper, nickel, nickel alloys, zinc, stainless and other alloy steels.

The next two chapters are devoted respectively to presses and tools, and one must agree with the wisdom of the author in his inclusion of these sections, in view of their profound influence upon the behaviour of the metal being pressed. The treatment of the subject of presses is very well suited to the main purpose of the book, mechanical details being restricted to those influencing the working of the metal. The chapter on tools gives an excellent account of the desirable properties of tool materials and then goes on to describe the materials which are available. As might be expected from a metallurgical author, the section on the heat treatment of tools is extremely well done.

A chapter on lubricants which follows, although not strictly metallurgical, is justified by the importance of the subject and the dearth of published information.

The testing of sheet metals is admirably dealt with in Chapter 12, and this is logically followed by a consideration of the properties which determine the behaviour of metal during deep-drawing. All the commonly practised and more original methods of testing are described, and the author's opinions regarding the value of the results have much to commend them. The tensile test is dealt with at some length, as the author is of the opinion that this test probably yields more useful information regarding the material than any other. It is not considered probable that any single test will be devised to measure the deep-drawing properties of sheet material.

Having described the effect of the various properties of sheet metal on its behaviour in pressing operations, the author proceeds to discuss the difficulties attending the drawing up of a specification for purchasing purposes. Finally, with commendable honesty, it is admitted that " the only essential clause which will attain the desired end seems to be one of a highly unscientific nature such as ' will produce the desired article with the desired surface finish.' " In view of this state of affairs the author stresses the importance of sincere co-operation between the suppliers and consumers of deep-drawing sheet. This chapter on specification must have been one of the most difficult to compose, and it should be read by all buyers and sellers of sheet metal.

The final chapters of the book, dealing with new applications of deep-drawing and pressing and with desired improvements in metal and press-shop procedure, are full of interest. A neat and very human epilogue rounds off the argument, and the volume concludes with an appendix giving an extremely useful and concise account of the application of X-ray examination to the study of deep-drawing materials and products, and an invaluable list of references to the literature of deep-drawing and pressing.

The author is to be congratulated on the profusion of most interesting illustrations of an extremely high standard of excellence. The quality of their reproduction and clarity of the printing of the book reflect great credit on the printers and publishers.

This book is an entirely praiseworthy production, which can be most strongly recommended to everyone connected directly or indirectly with the deep-drawing and pressing industry.

<div style="text-align: right">J. C. ARROWSMITH.</div>

ORES—MINING AND TREATMENT

The Properties of Swedish Iron Ores. T. Quennerstedt. (Jern-kontorets Annaler, 1940, vol. 124, No. 4, pp. 117–168). (In Swed-ish). In 1933 the Technical Council of Jernkontoret embarked on a programme of gathering and collating information on the properties of Swedish iron ores. A questionnaire was sent out to a large number of companies and persons with experience in the handling, treatment and reduction of these ores. The main points on which information was sought were : (1) The hardness of the ore in relation to breaking by manual labour and by power-driven crushers ; (2) its behaviour during roasting, sintering and briquetting ; and (3) its reduction in the blast-furnace. The author was also charged with the tasks of surveying the literature, both old and new, on these ores, of examining the replies to the questionnaire and, where useful information might result, of seeking interviews with some of those who had sent in replies. In this paper the author presents his survey of the literature which has included an examination, not only of technical papers by authorities on the subject, but also of text-books, hand-books and historical notes published by mining companies. Whilst most of the references are of course to Swedish writers, English and German authors are also quoted. Some tables of the properties of Swedish ores are included and a bibliography of 145 references is appended.

Differential Grinding of Alabama Iron Ores for Gravity Concen-tration. W. H. Coghill and P. H. Delano. (United States Bureau of Mines, June, 1940, Report of Investigations No. 3523). The authors give an account of some experiments on the beneficiation of Alabama red iron ores and ferruginous sandstones. Differential grinding—that is, the reduction of the soft particles whilst the hard particles are left in their natural state—was successfully applied. The remarkable result of differential grinding is that the hematite is greatly reduced in size and liberated while the sand is not attacked, so that, when this method is properly applied, much of the hematite may be taken off by the desliming methods commonly used in conjunction with milling.

Concentration of Manganosiderite Ore from Leadville, Colo. F. D. De Vaney and S. M. Shelton. (United States Bureau of Mines, May, 1940, Report of Investigations No. 3513). The authors report on an investigation of the large deposits of man-ganiferous iron ore known to be associated with the lead and zinc veins in the Leadville district of Colorado. In the unoxidised

portion of the veins the manganese is present as manganosiderite, and disseminated through this there are small amounts of galena, sphalerite, pyrites, siderite, feldspar and quartz. The manganosiderite can be separated from the sulphides and siliceous gangue by flotation. After calcining, the concentrate contained $21 \cdot 78\%$ of manganese, $41 \cdot 11\%$ of iron, $2 \cdot 9\%$ of silica and $0 \cdot 051\%$ of phosphorus. It is considered that this concentrate is suitable for making spiegeleisen.

REFRACTORY MATERIALS

Anomalies in the Properties and Behaviour of Silica Bricks.
C. Edwards and H. M. Spiers. (Transactions of the British Ceramic
Society, 1940, vol. 39, July, pp. 210–231). During the routine
testing of silica bricks, it was found that certain bricks from a
particular source were characterised by a much lower after-expan-
sion than would have been expected from their true specific gravities,
and that they gave a rather dead ring when struck. An explana-
tion for the behaviour of the bricks was sought by means of an
investigation which covered the following points : (1) The manu-
facturing conditions, including the kiln-firing ; (2) the nature of the
rocks employed for the manufacture of the bricks ; (3) the grading
of the brick mixture ; (4) the chemical composition of the bricks ;
and (5) the effect of heat treatment on the physical properties and
crystallographic structure of the bricks. The authors concluded
from the data obtained that the weak structure was due to an
excessive content of fines in the brick mixture and to a too rapid
rate of temperature rise in the final stages of the kilning. From
the investigation in question the authors also make the following
general deductions : (a) The true specific gravity of well-burnt
silica bricks of certain types may increase if the bricks are refired
to a high temperature subsequent to manufacture. This increase
may take place in the kiln itself if the firing temperature is excessive ;
(b) in cases where the increase in specific gravity has occurred during
the kiln-burning after a minimum value has been attained, sub-
sequent heat treatment at temperatures of $1450°$ or $1500°$ C. does
not again reduce the specific gravity, but tends, rather, to increase
it still further ; (c) bricks of this nature generally show but a small
after-expansion when tested at $1450°$ or $1500°$ C. ; (d) in the case
of bricks which have a true specific gravity of $2·36$, no views based
solely on specific gravity can be expressed as to whether the kiln
treatment has been adequate to secure complete conversion of the
quartz ; (e) the occurrence of an increase in true specific gravity
would seem to be associated with a high alumina and/or lime
content, and, with a silica content below 95%, it may be ascribed,
at least partially, to conversion of tridymite into cristobalite. It
takes place chiefly in the case of bricks containing little or no
quartz and having specific gravities not exceeding $2·35$; (f) the
development of a weak structure is generally due to an excessive
rate of conversion of the quartz, leading to differences between the
expansions of the matrix and of the coarser grains. As a result,

strains are developed and cracks are formed. These effects are accentuated if a high proportion of fines is present. Bricks which have a weak structure due to these causes are almost invariably oversize ; (g) in bricks containing a high proportion of fines the development of a further proportion of glassy matter would necessarily require exposure to a very high temperature, since the matrix would be relatively free from fluxes ; and (h) the existence of another form of silica with a true specific gravity rather higher than that of crystobalite seems to be a possibility.

Expansion of Various Refractories. A. M. Morton. (Blast Furnace and Steel Plant, 1940, vol. 28, July, pp. 665–666). The author makes some observations from his own experience concerning the expansion of refractory bricks in industrial furnaces. He recommends the use of a basic cement containing sufficient flux to take up expansion when laying magnesite bricks in preference to making expansion joints in the construction of open-hearth furnaces.

Slag Action of Alkalies on Refractories. T. L. Hurst. (American Refractories Institute, July, 1940, Technical Bulletin No. 75). The author presents in a concise and non-technical manner some of the conclusions reached as a result of experimental work in recent years on the effect of alkalis on refractory materials at elevated temperatures. The alkalis which are dealt with include potash vapour, vapour from potash-silica glass, potassium and sodium chloride vapours and sodium carbonate vapour.

FUEL

Utilisation of Waste Heat. S. G. Saunders. (Journal of the Institution of Heating and Ventilating Engineers, 1940, vol. 8, Aug., pp. 209–243). The author discusses schemes for the utilisation of waste heat and presents in comprehensive form the essential data required for estimating the potentialities of waste-heat recovery from reciprocating steam engines, steam turbines, internal combustion engines, cooling water systems, re-evaporated steam and sewage gas. He also makes recommendations regarding the design and application of waste-heat boilers.

Carbonising in Charcoal Kilns and Local Small-Scale Charcoal Burning. H. Bergström. (Jernkontorets Annaler, 1940, vol. 124, No. 6, pp. 265–273). (In Swedish). The author describes with numerous diagrams and illustrations the technique of stacking timber, the design of kilns and the arrangements to control the air supply as practised for charcoal burning on a large and small scale in Sweden.

The Coking Industry of India. (Coke and Smokeless Fuel Age, 1940, vol. 2, Sept., pp. 205–209). A review of the growth and present position of the coking industry of India is presented. It includes some data and illustrations concerning the coke-oven plant at the Jamshedpur plant of the Tata Iron and Steel Co., Ltd. Most of the information given is based on a recent paper by Haigh. (*See* p. 90 A).

PRODUCTION OF IRON

Recent Developments in Blast-Furnace Blower Design. R. M. Rush. (Eastern States Blast Furnace and Coke Oven Association: Blast Furnace and Steel Plant, 1940, vol. 28, July, pp. 678–679, 682, 707, 708). The author discusses developments which have taken place in America since 1928 in the design of steam turbo-blowers for blast-furnace blast. He gives particulars of two blowers (of 75,000 and 85,000 cu. ft. per min. capacity respectively) supplied to the Great Lakes Steel Corporation. In conclusion the author discusses some data submitted by the De Laval Steam Turbine Company relative to the design of a self-fired turbo-blower for blast-furnace requirements. This is really a turbine driven by hot air. The proposed plant is designed so that 74,500 cu. ft. of air per min. are mixed with 8100 cu. ft. of blast-furnace gas per min. in a combustion chamber to produce the driving medium. The gas first mixes with the proper amount of air for combustion and is kept lighted by standard electric ignition equipment. The additional air from the main blower mixes with the products of combustion to bring the temperature down to about 1500° F. The mixture of burned blast-furnace gas and cooling air is then expanded to a pressure of 19·3 lb. per sq. in. and a temperature of 1500° F. through the main gas turbine to atmospheric pressure, a process which reduces the temperature to 1170° F. The main gas turbine drives the air compressor, which is designed to supply 60,000 cu. ft. per min. at 22 lb. per sq. in. to the blast-furnace, and 74,000 cu. ft. per min. back to the combustion chamber for recirculation in the main gas turbine. The heat of the exhaust gases from the main gas turbine is utilised in a heat exchanger which reduces the temperature of the exhaust to 450° F. and raises the temperature of the air passing to the combustion chamber to 950° F. The net result is expected to be the production of 60,000 cu. ft. per min. of blast with a consumption of 8100 cu. ft. per min. of blast-furnace gas with a thermal efficiency of about 26% for the whole cycle.

Titanium in Blast-Furnace Hearths. S. Jansson. (Jernkontorets Annaler, 1940, vol. 124, No. 6, pp. 274–276). (In Swedish). The author describes a copper-coloured crystalline mass which has been found when removing the hearth of a blast-furnace at Domnarfvet in Sweden. This material formed a layer 5–20 mm. thick in the joints of the fourth layer of bricks from the hearth surface, and the adjacent brick surfaces were transformed to a grey slaggy substance containing a little iron. An analysis of the crystalline mass showed that it contained 3·8% of iron, 2·2% of carbon, 2·68%

of manganese, 2·2% of vanadium, 1·4% of silicon, 0·38% of sulphur, 16·8% of nitrogen and 69·8% of titanium.

Modifications in the Properties of Coke on Reheating in the Blast-Furnace. (Iron and Coal Trades Review, 1940, vol. 141, Aug. 30, pp. 217–218). It is known that as the coke descends in the external zone in a blast-furnace it is preheated to a temperature between 1400° and 1600° C. before it enters into combustion, so that the normal carbonising temperature is exceeded by about 500° C., and it has been suggested that this preheating before chemical reaction with the charge may account for various obscurities in the behaviour of blast-furnaces. In the present article some experiments, chiefly those of Wilde and Daub, to test this theory are discussed. From laboratory tests on a number of German and Silician coals the authors conclude that, as soon as the carbonisation temperature of a coke is exceeded, a transformation into pure graphite commences. As a result of the expulsion of contained gases, graphitisation of the carbon, and reduction and volatilisation of the ash, the whole energy balance of the coke is displaced, so that the temperatures to which the coke is subsequently raised during its second course of heating in the blast-furnace may lead to fundamental changes in its characteristics and composition. It appears that the nature and extent of the changes wrought depend on the nature of the original coal, and particularly on its rank.

Effect of Magnesia and Low Alumina in Blast-Furnace Slags on Furnace Operation and Desulphurization. L. F. Sattele. (Eastern States Blast Furnace and Coke Oven Association : Blast Furnace and Steel Plant, 1940, vol. 28, July, pp. 659–664). The author discusses from a practical point of view the importance of magnesia in maintaining a low viscosity in blast-furnace slags high in lime and low in alumina while at the same time obtaining a high degree of desulphurisation. He commences with a review of the blast-furnace practice over the last twelve years at the works with which he is connected. This review shows how the changes in the specification of the pig iron and in the analysis of the raw materials used created the slag problem. He then describes the practice which was developed to solve it. His conclusions are as follows : (1) A successful blast-furnace practice can be developed for slags containing under 10% of alumina with a total basicity of 53–55%, provided the magnesia content of the slag is over 4% ; (2) working with a low-alumina and highly basic slag contributes to a satisfactory production of iron with low fuel consumption and economic flue-dust practice ; (3) an excellent control of the sulphur can be obtained with the practice developed, as no casts were produced with sulphur exceeding 0·050%, the average content being about 0·030% ; and (4) if the slag basicity exceeds 55% the degree of desulphurisation decreases.

On the Reduction of Iron Ore with Carbon Monoxide, Hydrogen and Methane. M. Wiberg. (Jernkontorets Annaler, 1940, vol. 124,

No. 5, pp. 179–210). (In Swedish). The author reviews the equilibria in the reduction of the oxides of iron by carbon monoxide, hydrogen and methane and attempts to calculate the approximate relation between the oxygen content of wüstite and the composition of the gases at equilibrium in the wüstite region. On the basis of these calculations he completes the equilibrium diagrams with oxygen-content curves for the systems Fe–C–O and Fe–H–O and establishes the boundaries of the wüstite region in the Fe–O equilibrium diagram. The reactions $H_2O + CO \rightleftarrows H_2 + CO_2$ and $C + 2H_2 \rightleftarrows CH_4$ are important in the reduction of iron oxides, and the author has worked out the relation between the equilibrium constant and the temperature up to 2000° C. for the first reaction and up to 1200° C. for the second ; he has also estimated the amount of methane produced when mixtures of carbon monoxide and hydrogen are used as reducing agents. From thermal studies of the reduction of iron oxides with different gases he has established that when pure carbon monoxide is used the temperature rises about 100–150° C. With pure hydrogen on the other hand the temperature falls about 350° C. There is no change in temperature when a mixture of 64% of carbon monoxide and 36% of hydrogen is used. Reduction with methane or coke-oven gas requires the supply of so much heat that it is only practicable in retorts. The author puts forward proposals for the reduction of ores with coke-oven or natural gas. Comparative tests with carbon monoxide and hydrogen at 1000° C. have demonstrated that reduction is much more rapid with the latter up to the point when about 75% of the oxygen has been removed. After this point the rate of reduction with hydrogen diminishes much more rapidly than the rate with carbon monoxide, so that the total time required is longer with hydrogen than with carbon monoxide. A microscopical examination of the ore in various stages of reduction showed that the greater speed of the process towards the end when using carbon monoxide is probably due to its carburising action on the iron which forms a thin shell round the small wüstite grains. The reaction between the carbon in the austenite and the oxygen in the wüstite produces a gas at high pressure in the grain boundaries ; this bursts the iron shell and permits the carbon monoxide to penetrate and continue the reduction. When hydrogen is the reducing agent, hydrogen, but not steam, can diffuse through the iron shell ; in this case the pressure in the boundary layers is quite low and the reduction is therefore slower. When reducing with pure carbon monoxide at 1000° C., the iron can be carburised to form not only saturated austenite but even pure cementite. The experiments with pure carbon monoxide showed that carbon is probably capable of diffusing in cementite and that this therefore does not maintain the composition Fe_3C but is capable of dissolving some carbon or iron or both ; the equilibrium diagram should therefore show a region of homogeneity. When the reduced iron is subjected to long carbur-

isation with carbon monoxide at about 1000° C., the cementite disintegrates with the formation of free carbon, after which there is a considerable precipitation of carbon from the gases. A reduction test with a crystal of pure magnetite at 1000° C. was not completed because three substances were formed, namely, a core of ferroso-ferric oxide, an intermediate layer of wüstite and a surface layer of metallic iron; this proved that the movement of oxygen through the wüstite layer takes place by diffusion in solid solution. The reduction does not produce porosity in the wüstite layer, only large isolated cracks.

A bibliography of 38 references is appended.

Smelting Domestic Chrome Ores in the Electric Furnace. R. G. Knickerbocker, M. B. Royer and T. E. Evans. (Engineering and Mining Journal, 1940, vol. 141, July, pp. 49–51). The authors report briefly on an investigation by the U.S. Bureau of Mines of the reduction of iron-chromium concentrates obtained from Montana and Oregon. Open-top, short-shaft electric-arc furnaces were used and the object was to determine the degree of reduction possible, the power consumption and the grades of products obtainable by this means. The general conclusions reached were: (1) For the production on an industrial scale of standard ferro-chromium from American chromite high in iron, the electric furnace should be designed so that the iron-chromium alloy can be tapped off from the bottom; the molten slag, rich in chromium, can then be reduced to standard ferro-chromium without transferring it to another furnace with consequent loss of thermal energy. The standard electrode-hearth type of arc furnace is recommended for this operation; (2) basic chrome-magnesite refractories comparing favourably with those now available can be made from these American ore concentrates; and (3) further investigation of the slag systems arising during the process described is recommended.

Manufacture of Ferro-Silicon in the Blast Furnace. (Iron and Coal Trades Review, 1940, vol. 141, Sept. 20, p. 284). A review is presented of the results achieved in the course of investigations in Russia on the manufacture of ferro-silicon in small blast-furnaces. The work of V. Voronin and his collaborators has already been reported. (*See* Journ. I. and S.I., 1940, No. I., p. 318 A).

Slag Systems. R. Hay and J. White. (Journal of the West of Scotland Iron and Steel Institute, 1940, vol. 47, Mar., pp. 87–91). The authors discuss some of the lime-bearing slag systems which are of interest in blast-furnace and basic open-hearth practice. They describe an investigation of melts of lime and ferrous oxide in which the appropriate mixtures were made into pellet form; these were melted in small platinum capsules in an atmosphere of nitrogen in a closed pythagoras tube. The experiments proved conclusively that no such binary system as CaO–FeO exists. It appears that ferrous oxide in the presence of a powerful base, such as lime, undergoes dissociation as expressed by the equation $3FeO = Fe_2O_3 + Fe$

the iron reacting with the molybdenum or platinum of the crucible, and the ferric oxide combining with lime to form $2CaO.Fe_2O_3$.   The complete reaction can be written :

$$2CaO + 3FeO = 2CaO.Fe_2O_3 + Fe.$$
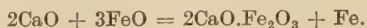
The phrase rule necessitates that this should go to completion, as only the three solid phases can co-exist at equilibrium in a three-component system ;   the products must therefore be either FeO, $2CaO.Fe_2O_3$ and iron or CaO, $2CaO.Fe_2O_3$ and iron, depending on whether CaO or FeO is present in excess.   In the light of the foregoing, the experimental results can only be adequately discussed in terms of the ternary system $CaO–Fe–Fe_2O_3$; this was confirmed by the microscopic examination of the products of the melts, which showed that free lime and free ferrous oxide never exist together in the same melt ; hence $Fe–2CaO.Fe_2O_3$ must be a true binary system.   The authors then proceed to examine the lime/silica/iron-oxides system which is made up of the components CaO, SiO_2, FeO and Fe_2O_3 and consequently forms a quaternary system. They refer to other investigators' work on three of the four ternary systems formed by these components, and then describe some experiments of their own on the $CaO–Fe_2O_3–SiO_2$ system.   They prepared a series of mixtures of these three components in pellet form and determined their melting points.   By subsequent microscopic examination it was possible to determine the phases present at the freezing temperature of the various mixtures.   The mixtures rich in ferric oxide gave melts which contained magnetite among other constituents.   It is of interest to note that when silica predominates over lime the background is light grey and when lime predominates it is a eutectic.   From all the data obtained it has been possible to deduce with a fair degree of certainty the phase relationships occurring in the quaternary system $FeO–Fe_2O_3–CaO–SiO_2$ at various temperatures.   It can be said in general that in a quaternary diagram the various co-existing phases are indicated by dividing the tetrahedron representing the quaternary system into volumes of four-phase equilibrium, the dividing planes being themselves planes of three-phase equilibrium bounded by lines of two-phase equilibrium.   They present a quaternary representation of this system at 900–1000° C. which shows how the proportions of magnetite, fayalite, olivines, ortho-silicate, &c., vary with composition.   This diagram is valuable in the study of the reduction of iron ores and the production of sinters, as it indicates how their composition can be controlled to the best advantage.

PRODUCTION OF STEEL

Modern Alloy Steel Manufacture. W. C. Kernahan. (Blast Furnace and Steel Plant, 1940, vol. 28, July, pp. 671–676). An illustrated description is given of the electric furnaces, ladles, ingot moulds and stripping plant at the works of the Copperweld Steel Co., Warren, Ohio. (*See* p. 138 A).

Vanadium-Alloys Steel Company—A Pioneer Maker of Alloyed Steels. C. Longenecker. (Blast Furnace and Steel Plant, 1940, vol. 28, June, pp. 599–602). The author describes the growth of the Vanadium-Alloys Steel Company at Latrobe, Pennsylvania, its present plant and the various processes involved in the manufacture of finished tools of vanadium steel.

A Metallurgical Survey of Machine Cutting Tools. H. W. Pinder. (Metallurgia, 1940, vol. 21, Mar., pp. 160–162). The author enumerates the properties desirable in a tool steel and briefly discusses the factors governing the casting of a tool-steel ingot, its hot-working and subsequent heat treatment, and describes the methods of manufacturing tools made of tungsten carbide; tungsten and titanium carbides; and tungsten, titanium and tantalum carbides.

Operations on the Pit Side of a Modern Openhearth. G. D. Tranter. (Metal Progress, 1940, vol. 38, July, pp. 49–53). The author reviews open-hearth practice as carried out on the casting side of the furnace. He discusses the use of two nozzles and oval nozzles in the bottom of the ladle, the cleaning of ingot moulds, defects in rimming and killed steel ingots and the training of furnacemen.

Eliminating Gas Losses on Reversing Open-Hearth Furnaces. (Foundry Trade Journal, 1940, vol. 63, Sept. 19, p. 194). Some data are presented which show that the loss of fuel gas during the time taken in the reversing of a fuel valve of an open-hearth furnace may be as much as 2·5% of the total gas consumption. A description is then given of a mechanism designed by Pszczolka which obviates practically the whole of this loss. The device consists essentially of a magnetically operated throttle valve inserted in the gas main as close as possible to the mushroom valve; this throttle valve is normally open but is closed during the change-over operation. The electromagnet controlling the throttle valve is connected in parallel with the motor driving the mushroom valve, and the former valve can be opened or closed in 0·7 sec.

The Mechanism and Conditions of Carbon Elimination in Open-Hearth Furnaces with a Deep Bath. S. Sapiro. (Stal, 1939, No.

10–11, pp. 23–25). (In Russian). Some data from the Kirov works concerning open-hearth furnaces operated with a depth of bath of 1·5–1·6 m. are considered. A study of the melting of medium carbon steels with appreciable variations in the carbon content after melting, and of the rate of elimination of the carbon shows that the latter factor appears to have no effect on the temperature of the metal on tapping, which, on the average, amounts to 1510–1515° C. The temperature of the metal is therefore dependent on the heating capacity of the furnace rather than on the rate of carbon elimination. Subsequent discussion leads to the conclusion that carbon elimination should be rapid, because this assists in the removal of hydrogen and produces a sounder and more ductile steel. This is borne out by works data. There is no connection between the rate of carbon elimination and the austenite grain size. It has been found that with an increase in the depth of the bath the rate of carbon elimination is slowed down, owing to the comparatively inactive zone near the bottom. This is also associated with poor degassification of the metal. This latter drawback can be remedied by increasing the amount of carbon to be eliminated during the boil as the depth of the bath is increased.

Manganese Losses in Open-Hearth Practice. (Foundry Trade Journal, 1940, vol. 63, Sept. 12, pp. 175–178 ; Sept. 19, pp. 191–192). An abridged English translation is presented of Bardenheuer and Henke's paper on methods of preventing the movement of manganese from the steel to the slag in open-hearth practice. This paper appeared originally in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 16, pp. 243–260. (*See* Journ. I. and S.I., 1940, No. I., p. 80 A).

Additional Information about the " Kirov " Method of Melting High Alloy Steels. I. Nikonov. (Stal, 1939, No. 10–11, pp. 27–29). (In Russian). In the Kirov method the steel is melted under a small quantity (1–2%) of semi-acid slag in a basic electric-arc furnace. In the present paper special reference is made to the application of the Kirov method to high-alloy, stainless, acid- and heat-resistant steels. The charge should contain not more than 0·40% of carbon, not more than 0·20% of chromium and not more than 0·050% of sulphur. Immediately after melting, the carbon content should be 0·25–0·35% and the manganese content 0·4–0·6%. During melting 1·5–2% of lime is added to form a slag. Oxidation to eliminate phosphorus should be complete in 15–20 min. When the carbon has been reduced to 0·10–0·08%, the slag is almost completely removed and ore is added to reduce the carbon content to 0·02%. After the boil (40–50 min.), 75% of the slag is removed. For refining, the bath is treated with aluminum, ferro-silicon, crushed fire-clay and manganese. After deoxidation and the formation of a thin fluxing layer, preheated ferro-chrome is added in portions. The metal is stirred after the ferro-chrome has melted, the slag being treated with 5% ferro-silicon, after which the current is switched off

and ferro-titanium is added if required. Finally the current is switched on for 3–4 min. The whole refining period lasts 90–95 min. The slag analyses were :

					After Melting. %	On Tapping. %
SiO_2	.	.	.	.	30·8–43·0	34·3
CaO	.	.	.	.	12·9–23·4	19·2–30·2
MgO	.	.	.	.	10·0–23·8	22·0–30·4
FeO	.	.	.	.	5·5– 7·6	1·1– 2·4
MnO	.	.	.	.	0·8– 1·5	Trace– 1·52
Al_2O_3	.	.	.	.	Trace–14·8	2·7– 3·3
Cr_2O_3	.	.	.	.	13·4–17·4	Trace– 2·0

The advantages of the process are : (a) Increased furnace output ; (b) reduced energy and electrode consumption ; (c) better utilisation of the ferro-titanium ; and (d) prolonged roof life. The resistance of the furnace lining to the action of the slag was good and the quality of the steel obtained was excellent. The metal was free from gas, but contained small amounts of nitrogen, which is considered beneficial in these steels. The only drawback to the process is the ineffective desulphurisation and consequently the sulphur content of the charge must be low. Experiments on the adaptation of the process to the open-hearth are in progress. It is also stated that a steel of lower flaking sensitivity is produced.

FORGING, STAMPING AND DRAWING

General Principles of Die Design and Some Recent Developments in Die Making Practice. B. G. Ross. (Australasian Engineer, 1940, vol. 40, July 8, pp. 10–11, 34–38). The author discusses the following points of importance in connection with die-making practice : The proper classification of various types of dies ; stock used for press work ; punch clearance in blanking and piercing ; where to apply punch clearance ; die clearance ; speeds and feeds for presses ; pressure required for punching ; economics in laying out blanking dies ; the relation between the form of stamping and the direction of the grain of the stock ; types of piercing punches and methods of holding ; preventing punchings from sticking in the die ; the use of Cerromatrix (an alloy of bismuth, lead, tin and antimony which expands upon cooling) for fixing punches and dies ; and hobbing.

How to Forge Tool Steel. A. M. Steever. (Iron Age, 1940, vol. 146, July 25, pp. 21–27). The author describes the heating and forging operations necessary in the production of billets and bars from ingots of tool steel and gives some information on the correct rates of heating and the maximum and minimum forging temperatures for this class of steel.

Fabrication of Stainless Steel Into Chemical & Process Vessels. P. L. Coddington. (Metal Progress, 1940, vol. 38, July, pp. 39–44). The author discusses many points relating to specifications for the manufacture of vessels of stainless steel and offers several practical suggestions to both the designers and users of such vessels.

Stainless Steel in Aircraft Fabrication. H. W. Perry. (Steel, 1940, vol. 107, Aug. 5, pp. 72–75). The author describes some of the pressing and welding operations employed in the fabrication of aeroplane wings from stainless steel sheet and strip. He states that although the cost of manufacturing one stainless steel wing is much greater than if aluminium were used, when one hundred or more are required the cost of the special tools is spread over the larger number with the result that stainless steel wings then become cheaper than aluminium ones.

The Belgian Wire Industry. L. J. C. Lepage. (Wire and Wire Products, 1940, vol. 15, July, pp. 358–361, 378). After briefly describing the process of wire-drawing, the author gives a brief account of the methods employed in Belgium for the manufacture of nails, rivets, wood screws, bolts, barbed wire and netting. He concludes with some statistics relating to the productive capacity, capital and sales organisation of the Belgian wire industry.

Lead as a Lubricant in Wire Drawing. C. L. Mantell. (Wire and Wire Products, 1940, vol. 15, July, pp. 353–356, 371). The author describes the plant and procedure employed for wire-drawing, using lead as a lubricant. The application of lead is particularly successful when drawing rods of stainless steel. He states that with this process there is no need for an intermediate annealing and pickling of the wire, that the die-wear is very slight, and that a very smooth and clean surface is left after removing the lead.

ROLLING-MILL PRACTICE

Some Aspects of Rolling. J. F. Whitfield. (Proceedings of the Cleveland Institution of Engineers, 1940, Apr., No. 6, pp. 213–249). The author studies the theory of hot-rolling. He states that, with the exception of modern continuous mills, the efficiency of a mill stand considered as a mechanical unit is generally low, and, so that the reasons for this may be better understood, he reviews the nature of the work which the rolls and stand are called upon to do and outlines the principal factors which influence their efficiency. In an appendix he shows how to calculate the separating force, rolling torque and energy requirements in the hot-rolling of plain carbon steel.

Electrification of the Bloom and Rail Mills. A. H. Kinley. (B.H.P. Review, 1940, vol. 17, June, pp. 10–12). The author presents an illustrated description of the electric motors and equipment installed in 1939 at the Newcastle Works (New South Wales) of Broken Hill Proprietary Co., Ltd., to drive the blooming mill and the rail mill. The main motors for these two mills comprise one 7000-h.p. and one 6700-h.p., 1300-V., D.C. motor, both arranged for Ward-Leonard control. This electrical machinery replaces the steam engines previously used.

Shearing of Bar Steel. D. M. Henderson, jun. (Iron Age, 1940, vol. 146, July 18, pp. 33–35). The author reports on an investigation of the hardness and type of section produced when hot-shearing steel bars $3\frac{1}{4}$ in. square and $2\frac{1}{4}$ in. $\times \frac{1}{2}$ in. From the results obtained he determined the blue-brittle range of the steel. If the bars were sheared at temperatures in this range they were partly cut and partly broken; if sheared at temperatures above or below this range a true cut was obtained. In conclusion the author gives the blue-brittleness temperature and colour of the fracture for steels of different carbon contents.

HEAT TREATMENT

Liquid Carburising. M. Stewart. (Australasian Engineer, 1940, vol. 40, July 8, pp. 14–15). The author deals in an elementary way with the technique of liquid carburising, describing the furnaces used and considering possible bath compositions, with special reference to certain deleterious contaminations. In addition he discusses which qualities of steel are suitable for liquid carburising and gives tabular data showing the effect of the temperature and composition of the bath and the duration of the treatment on the resulting case depth and hardness of a variety of steels.

The Process of Cyanide Hardening. D. McPherson. (Machine Shop Magazine, 1940, Aug., pp. 82–85). The author discusses the properties of sodium cyanide and describes the processes of case-hardening in molten sodium cyanide, of pack-carburising and of gas-cyaniding. He explains that in gas-cyaniding the carburising gas has to be introduced at the charging end of the furnace and the ammonia at positions along the muffle where the work has attained the necessary temperature. In this process a film of amorphous carbon is formed at the surface of the work, and when this carbon reaches the full-temperature zone of the furnace it reacts with the ammonia introduced at this point to form gaseous hydrocyanic acid at the metal surface ; when this gas is formed from its elements within the furnace there appears to be no risk of poisoning. The effect of ammonia upon the carburising reaction is very marked, and it is possible to carburise at temperatures very much lower than the usual carburising temperature, even as low as 620° C.

Surface-Hardening Machine. (Engineering, 1940, vol. 150, Sept. 20, pp. 227–228). An illustrated description is given of an improved machine manufactured by the Shorter Process Co., Ltd., for the hardening by the Shorter process of spur gears, bevel gears, single and double helical gears and straight surfaces. The Shorter process of flame-hardening has been described previously. (*See* p. 148 A).

Gray Cast Iron—A New Heat Treatment. (Iron Age, 1940, vol. 146, Aug. 1, pp. 52–54). **A New Heat Treatment for Gray Cast Iron.** E. L. Bartholomew. (Steel, 1940, vol. 107, Aug. 5, pp. 60–64). The author briefly describes a form of heat treatment for grey cast iron that is similar to that known as austempering which is applied to steel, and discusses the improvement in properties obtained with it. The specimens used by the author were heated to 1550° F., held at this temperature for 15 min., quenched and held at 510° F.

for 15 min. and then allowed to cool in air to room temperature.
He presents some micrographs and test data of specimens treated
in this way. It is of interest to note that the damping capacity
of the iron was unaffected by this form of heat treatment.

Heat Treatment of Malleable Iron. R. J. Cowan. (American
Foundrymen's Association : Foundry Trade Journal, 1940, vol. 63,
Sept. 5, p. 153). An extended abstract of the author's paper
which appeared in Steel, 1940, vol. 106, Mar. 25, pp. 44–47, 72, 80,
is presented. (*See* p. 16 A).

A Tubular Furnace. J. H. Loux. (Steel, 1940, vol. 107, Aug. 5,
pp. 54–55). The author describes a horizontal cylindrical furnace
for the heat treatment of tubes from 2 to 14 in. in dia. The furnace
is over 100 ft. long and has a capacity of 20 tons per hr. It has a
power-driven roller hearth and is fired by natural gas from burners
placed above and below the rollers and tangentially to the cylindrical
chamber. The temperature of the furnace can be maintained
within very close limits whether it is being used for normalising
at 1750° F. or tempering at 800° F.

The How and Why of Time Quenching. J. L. Burns. (Machinist,
1940, vol. 84, Sept. 14, pp. 523–526). The author describes three
methods of time-quenching carbon steels. These are : (1) To
quench in one liquid medium for a predetermined period, then
withdraw the article and cool to room temperature in air ; (2) to
quench in water for a limited period, and then cool to room tempera-
ture in oil ; and (3) interrupted quenching, in which the part is
withdrawn from a single liquid medium and then replaced in it
for the final cooling. He reproduces several series of curves in
which the hardness of 0·40% and 0·60% carbon steel specimens
quenched by these methods is plotted against the distance from the
centre.

Straightening Hardened Parts. W. P. Boyle. (Steel, 1940,
vol. 107, July 22, pp. 46, 77). The author states that the straighten-
ing of tool steel and steel parts which have become distorted during
heat treatment is an operation calling for great skill and experience.
He makes some general recommendations for the guidance of those
engaged in this work.

WELDING AND CUTTING

Stainless Steel in Aircraft. C. de Ganahl. (Machinist, 1940, vol. 84, Sept. 14, pp. 527–529). The author describes the technique which has been developed at the works of Fleetwings Incorporated for the fabrication of aircraft wings, control surfaces and fuel tanks from stainless steel strip. Spot-welding has been highly developed for this purpose and machines capable of making 960 welds per min. are used.

Fabrication, Inspection and Testing of Engine Entablatures and Welded Pressure Vessels. S. F. Dorey. (Engineering Inspection, 1940, vol. 5, Summer Issue, pp. 23–29). The author describes and discusses the essential factors involved in the production of sound and efficient welded components with particular reference to marine-engine bedplates and entablatures and to welded pressure vessels. He deals at some length with the inspection and testing procedure as applied both during and after manufacture.

Welding Metallurgy. Part VIII. The Solid Weld. O. H. Henry and G. E. Claussen. (Welding Journal, 1940, vol. 19, July, pp. 501–508). Continuation of a series of articles (*see* p. 152 A). In this part of the series the authors study the changes in the temperature distribution during the single-pass and double-pass welding of iron and steel plates and the relation of these changes to the changes in the microstructure.

Oxyacetylene Gouging—A Flame-Machining Process. R. F. Flood. (Welding Journal, 1940, vol. 19, July, pp. 482–486). The author describes the machine- and hand-operated oxy-acetylene equipment which is used for cutting U-shaped grooves in the surface of steel, for removing weld metal from the underside of electric welds, for removing defective weld metal, and for preparing the edges of thick plates for welding. The burner nozzle used is designed to deliver a relatively large volume of oxygen at low pressure. The depth and width of the cut can be accurately controlled and the operation is more rapid than pneumatic chipping.

Machine Flame Cutting. H. C. Boardman. (Welding Journal, 1940, vol. 19, July, pp. 487–499). The author describes the equipment and technique employed for machine-operated oxy-acetylene cutting, giving numerous well illustrated examples of the application of the process.

Flame-Cutting Clad Steel. H. F. Lassner. (Welding Journal, 1940, vol. 19, July, pp. 500–501). The author describes a technique for the oxy-acetylene cutting of clad steel plate.

PROPERTIES AND TESTS

Static Crack Strength of Metals—Its Determination and Significance. M. Gensamer. (Metal Progress, 1940, vol. 38, July, pp. 59–64). The author refers to an earlier paper on the mechanical properties of the isothermal decomposition products of austenite (see Journ. I. and S.I., 1940, No. I., p. 48 A), in which a method of determining the cohesive strength of steel was described, as well as to the method of preparing notched specimens described by Kuntze in his book " Kohäsionsfestigkeit " published in 1932. In the present paper the author describes two methods of producing sharp circumferential notches in round steel specimens ; these require less time and skill than the method described by Kuntze. One method consists of machining a 60° notch and finishing this with an ordinary 60° triangular file that had been smoothed by rubbing two faces down on polishing paper or on a fine tool-sharpening stone. In the second method specimens 0·25 in. in. dia. and 2 in. long are prepared by cutting a notch to a depth of $\frac{3}{64}$ in. with a 60° lathe tool ; the notch is then polished with a grinding compound and finished with No. 400 carborundum ; a fatigue crack is then produced at the bottom of the notch by placing the specimen in a rotating cantilever-beam fatigue-testing machine fitted with a special switch to control the depth of the crack. Subsequent tensile tests of specimens with a fatigue crack show that the bottom of the crack seldom forms a perfect circle but is usually a fairly good ellipse, so that the area of the cracked surface and the area of the surface actually fractured in the tensile test can readily be calculated. For the tensile test the author has devised an alignment sleeve which surrounds the specimen holders and ensures that no bending moment is applied. Having described the method of preparing the specimens and testing, the author proceeds to discuss some of the results obtained and the factors influencing these results. In a subsequent letter (which appeared in Metal Progress, 1940, vol. 38, Aug., pp. 182, 204) the author defines more clearly the technical terms he uses and explains that he prefers the term " static crack strength " instead of " technical cohesive strength " for the force required to fracture a specimen having a fatigue crack or filed notch prepared as described above. The results of numerous tests of fatigue-cracked and file-notched specimens are plotted to show the relation between the crack depth and the static crack strength. In general, the results demonstrate that : (1) The static crack strength of a fatigue-cracked specimen is slightly lower than that of a file-notched specimen ; (2) increasing the depth of

the notch or crack increases the static crack strength; (3) anneal-ing the specimens in a vacuum decreases the static crack strength; and (4) if the specimens have been cold-rolled then the greater the percentage reduction in area by cold-work the greater is the static crack strength.

Static Crack Strength of Metals. D. J. McAdam, jun. (Metal Progress, 1940, vol. 38, Aug., pp. 180–181). In a discussion of Gensamer's paper on the static crack strength of metals (*see* pre-ceding abstract), the author explains Kuntze's method of calculating the cohesive strength of a cylindrical steel specimen with a V notch and how this differs from the static crack strength as deter-mined by Gensamer. When making the final tensile test on the cracked specimen Gensamer rejects the result if the load reaches a maximum and begins to diminish before fracture occurs, because this indicates plastic deformation preceding fracture. Such results are, however, the only ones that could be used according to Kuntze's method, which actually involves the determination of a series of values representing gradually decreasing plastic deformation, and the use of these values in linear extrapolation to obtain a value representing no plastic deformation.

Stress Raisers. G. Sachs. (Iron Age, 1940, vol. 146, Aug. 1, pp. 31–34; Aug. 8, pp. 34–37). The author surveys recent litera-ture on the effect of stress raisers such as notches, holes and cracks, on the tensile and impact strength of steel specimens.

The Static and Fatigue Torsion Strengths of Various Steels with Circular, Square and Rectangular Sections. E. G. Holley. (Pro-ceedings of the Institution of Mechanical Engineers, 1940, vol. 143, Sept., pp. 237–246). The author reports on his research into the comparative elastic and fatigue torsion strengths of bars of circular, square and rectangular cross-section, no data for the two last types of section having been published previously. The static torsion tests were carried out in a 10,000-lb.in. Avery machine. For the torsion fatigue tests the author constructed a special apparatus, which is illustrated and described in detail in the paper. t was designed to test specimens up to 0·9 in. in dia. and 6 in. in length, and to run at a speed of 1500 r.p.m. The tests were carried out with specimens of various qualities of mild steel, nickel-chromium steel, nickel steel and chromium-vanadium steel, including a chromium-vanadium high-carbon spring steel. The analyses and particulars of the heat treatment of these steels are given in the paper. The investigation led to the following results: (1) In the case of square and, in particular, of rectangular sections the use of enlarged ends leads to discrepancies between the experimental and theoretical values of the elastic torsion strengths; (2) provided that end effects are eliminated, the elastic torsion strengths of bars of rectangular section are in fair agreement with the theoretical values, up to the maximum ratio of the sides of the section adopted in the tests, *viz.* 3·5 : 1; (3) the elastic strains of bars of square

and rectangular sections agree closely with the theoretical values, irrespective of the form of the ends ; (4) the form of the ends of the test-pieces has a very pronounced effect on the torsion fatigue strength of bars of square and rectangular section, enlarged ends having a very considerable strengthening effect which masks the true strength ; (5) the torsion fatigue strengths of bars of the alloy steels studied are much lower for those of square and rectangular sections than for the corresponding ones of circular section. The author considers this to be due to the form of the peripheral stress gradients, and he compares the results with those obtained by Gough for circular shafts with keyways.

In conclusion the author discusses the value of the static properties of metals as criteria of fatigue strengths, and in an appendix he considers the problem of the raising of the elastic stress in a material where the distribution of stress is uneven.

The Problem of Fatigue Fracture : Magnetic Powder Pictures and Fatigue Fracture Cracks. (Metallurgia, 1940, vol. 22, Aug., pp. 125–126). Some investigations on the formation and propagation of fatigue cracks in steel are discussed. Particular reference is made to the relation between the number of stress reversals required to produce a crack and the additional number required to produce fracture. Some of the results obtained by Hempel are presented (*see* Journ. I. and S.I., 1939, No. II., p. 288 A).

On the Recovery of Fatigue Caused by Annealing. F. Oshiba. (Science Reports of Tôhoku Imperial University, 1940, vol. 29, June, pp. 69–82). The author reports on an investigation the object of which was to determine the annealing temperature and time which would produce the maximum recovery in fatigue strength of 0·2% carbon steel and Flodin iron. Specimens of the steel were annealed in hydrogen at 500°, 650°, 670°, 700°, 800° and 900° C. and the annealing time was varied between 30 min. and 10 hr. The results of subsequent impact tests are shown by graphs, from which it is seen that, at each temperature, the impact value increased at first, reached a maximum, then decreased and then increased again with increasing annealing time. The higher the temperature, the more rapid was the initial increase in the impact value, and the less was the time required to attain the maximum impact value.

Permanent Magnets. J. F. Kayser. (Engineer, 1940, vol. 170, Sept. 20, p. 183). The author reviews the major developments in the production of improved permanent-magnet steels and refers in particular to the revolution in manufacturing methods which is now about to begin. This revolution is based on the discovery that by allowing certain alloys containing cobalt, nickel, aluminium and iron to cool from the high heat-treatment temperature in a magnetic field of approximately 3000 c.g.s. units, permanent magnets with remanences in the vicinity of 12,000, coercive forces of about 600 and $BH_{max.}$ lying between 4,500,000 and 5,000,000 can be produced.

Manufacture of Permanent Magnets. J. C. Swan. (Iron and Steel, 1940, vol. 13, Aug., pp. 419–422). The author presents a general summary of the factors involved in the manufacture of small electro-magnets by (a) machining from bar stock; (b) blanking out from strip or sheet metal; (c) forging or pressing from bar; and (d) casting. In conclusion he discusses how the heat treatment affects the magnetic properties of chromium, tungsten and cobalt steels.

On the Longitudinal Magneto-Resistance Effect of Single Crystals of Iron. Y. Shirakawa. (Science Reports of Tôhoku Imperial University, 1940, vol. 29, June, pp. 132–151). The author examines the changes in the electrical resistance of single crystals of iron at room temperature in magnetic fields varying up to 1400 oersted and the effect of changing the direction of the axis of the crystal relative to the magnetic field. From the data obtained he plots magneto-resistance curves; these show that the resistance changes linearly with increase of field strength up to saturation value, after which the resistance remains constant. The anisotropy of magneto-resistance for iron is very large; it is most clearly seen in the plane (100), fairly clearly in the plane (110), but it is very small in the plane (111).

On the Longitudinal Magneto-Resistance Effect at Low Temperatures of Single Crystals of Iron. Y. Shirakawa. (Science Reports of Tôhoku Imperial University, 1940, vol. 29, June, pp. 152–161). The changes in the electrical resistance of three single crystals of known orientation and of a poly-crystal of iron was measured at temperatures of $0°$, $-95°$ and $-195°$ C. in magnet fields up to 1400 oersted. It was found that the magneto-resistance curves for these three temperatures for a bar consisting of a single crystal the axis of which coincides with one of the principal axes are very similar. As in the experiments at room temperature (see preceding abstract) it was seen that the anisotropy for iron is very large, and that it is especially so at very low temperatures.

On the Elasto-Resistance Change of Nickel, Iron and Some Nickel-Iron Alloys. N. Yamonaka. (Science Reports of the Tôhoku Imperial University, 1940, vol. 29, June, pp. 36–68). The author reports on an investigation of the changes in the electrical resistance of nickel, iron and nine nickel-iron alloys in a magnetic field when subjected to tensile stress.

The Thermal Conductivity of Ferrous and Non-Ferrous Alloys. J. W. Donaldson. (Metallurgia, 1940, vol. 22, Aug., pp. 115–119). The author reviews a number of recent investigations of the thermal conductivity and electrical resistivity of (a) pure iron; (b) carbon steel; (c) alloy steels containing nickel, chromium, molybdenum, copper, and aluminium; (d) grey and white cast irons; and (e) some non-ferrous metals and alloys.

Creep at High Temperatures. H. J. Tapsell. (Transactions of the North-East Coast Institution of Engineers and Shipbuilders,

1939–1940, vol. 56, pp. 153–164). The author describes the creep characteristics of metals with special reference to the behaviour of carbon and of molybdenum steels. The manner in which the tensile properties such as ultimate stress and limit of proportionality are influenced by creep is first dealt with, and then follows an account of the general behaviour of metals during creep and of the influence of temperature, stress and time. The latter half of the paper deals specifically with the creep properties of carbon and molybdenum steels. Considerable variations in the creep properties of carbon steels of similar carbon content have been encountered, and this important feature is well illustrated by the data provided, which also show that steels containing from 0·13% to 0·4% of carbon have much the same properties around 450° C. Molybdenum steels of similar composition also vary considerably in creep properties, although they are much superior to carbon steels. The addition of a small percentage of vanadium to molybdenum steels produces further improvement. The effect of heat treatment is described, particular attention being given to the effect of prolonged heating during service. Methods of estimating working stresses are given, and numerical data and curves show how experimental results may be utilised.

Creep Under Combined Tension and Torsion. Part I. The Behaviour of a 0·17 Per Cent. Carbon Steel at 455° C. H. J. Tapsell and A. E. Johnson. (Engineering, 1940, vol. 150, July 12, pp. 24–25; July 26, pp. 61–63; Aug. 9, pp. 104–105; Aug. 16, p. 134; Aug. 30, pp. 164–166). The authors refer to the existence of many theories concerning the creep of steel under complex stress systems, and they then describe an investigation, carried out at the National Physical Laboratory, of the creep of specimens of 0·17% carbon steel produced by combined tensile and torsional stresses at 455° C. The apparatus used is described in detail. The tests lasted 150 hr., and curves were drawn for the axial and circumferential creep in relation to time. From the test data obtained the authors calculate the creep rates at various values of tensile and torsional stresses and compare these with the rates obtained by applying the theories of Odqvist, Bailey, Soderberg and Marin. Attached to the paper are two appendices by A. E. Johnson.

Embrittlement of Creep Resisting Steels at High Temperatures. (Metallurgist, 1940, vol. 13, Aug., pp. 121–122). The results obtained by Siebel and Wellinger and by Scherer and Kiessler on the testing of steel for embrittlement at high temperature are considered and the reasons for some of the discrepancies are discussed. (*See* Journ. I. and S.I., 1939, No. I., p. 299 A and 1940, No. I., p. 300 A).

Properties of Metals at Low Temperatures. (Metallurgist, 1940, vol. 13, Aug., pp. 122–124). The conclusions arrived at in a number of recent papers on the testing at temperatures down to − 253° C. of iron, nickel, copper and lead, and of steel alloyed with (*a*) nickel, (*b*) nickel and molybdenum, (*c*) chromium and molybdenum,

(*d*) chromium, molybdenum and vanadium, and (*e*) nickel, chromium and molybdenum, are presented. Abstracts of the papers in question have already been published in the Bulletins of the Iron and Steel Institute.

Mechanical and Physical Properties of High Duty and Alloy Cast Irons. J. W. Donaldson. (Foundry Trade Journal, 1940, vol. 63, Aug. 29, pp. 141–144). The author discusses the methods of testing and the properties of high-duty cast irons and alloy cast irons containing nickel, chromium, molybdenum, copper, aluminium and tungsten. Several tables of properties are presented and these include thermal conductivity, expansion and specific heat, as well as the electrical and magnetic properties.

Heat and Corrosion Resistant Castings. D. W. Talbott. (Steel, 1940, vol. 107, July 22, pp. 40–44 ; July 29, pp. 38–40). The author discusses the properties and applications of a large variety of chromium-nickel-iron alloys, classifying them into those which are heat-resisting and those which are corrosion-resisting. He presents graphs showing the tensile strength and elongation at temperatures in the 1000–2000° F. range of the 15/35, 24/12 and 12/60 chromium-nickel steels as well as data on their Brinell hardness, impact strength, specific gravity, Young's modulus and coefficient of expansion. His information regarding the corrosion-resistant steels is confined mainly to their sphere of application.

Metallurgical Developments Applied to the Aircraft Industry. L. Sanderson. (Metallurgia, 1940, vol. 22, July, pp. 105–106). The author reviews some developments in the application of ferrous and non-ferrous alloys for aircraft construction. Of particular interest is a manganese-nickel cast iron for the cylinders of light, air-cooled, aeroplane engines.

Some Steel Developments Applied to Aircraft. L. Sanderson. (Metallurgia, 1940, vol. 22, July, pp. 99–100). The author reviews some recent developments in the application of steel in the manufacture of aircraft. He refers to the extended use of steel castings, especially in American aircraft, and gives particulars of a copper-silicon steel which is used for castings in the landing-gear mechanism. This steel contains carbon 0·12–0·2%, manganese 1·1–1·35%, silicon 1–1·25%, copper 1·5–2·0%, and phosphorus and sulphur each 0·045% max., and it has a good fluidity at relatively low pouring temperatures. He also mentions that the addition of a small percentage of silver to 18/8 stainless steel enhances its corrosion resistance when in contact with sea-water.

METALLOGRAPHY AND CONSTITUTION

Grinding for the Preparation of Metallographic Specimens.
T. Berglund. (Jernkontorets Annaler, 1940, vol. 124, No. 6, pp.
234–264). (In Swedish). As there appears to be little technical
information and data available on the relation between such factors
as the grinding time, velocity of the abrasive materials, coefficient
of friction, loss of weight of specimen, &c., in the preparation of
metallagraphic specimens, the author undertook a thorough investi-
gation of this subject, the results of which are reported in the
present paper. For this purpose he used a grinding machine
capable of revolving a horizontal abrasive wheel, 300 mm. in dia.,
at speeds in the range 45–800 r.p.m. The pressure on the specimen
could be varied up to 10 kg. ; the machine was also equipped with a
device (similar to that used by Honda and Yamada) for recording
the frictional forces. The specimens used were of a chromium-
nickel structural steel, 15–30 mm. in dia., hardened to Brinell 265.
Three types of polishing discs were used : (a) Aluminium discs to
which alundum polishing cloths were attached ; (b) lead discs with
a spiral groove to which a polishing medium of emery powder in
lard oil was applied ; and (c) moulded discs made up of 2600 g. of
alundum, 240 g. of paraffin and 160 g. of stearine. The conclusions
reached are deduced from the results of about 2500 tests. With all
three types of disc it was found that the rate at which material was
removed was similarly related to the three integrated factors polish-
ing speed, pressure and time. Owing to the relatively large spread
of the results the conclusions are based on a large number of repeated
tests ; this applies especially to the polishing with aloxite and
similar media with a grain size of 180–240. The speed of removal
decreases very rapidly with time, so that from the time-saving point
of view effective polishing is only achieved with new or almost new
polishing discs. Although the author's tests were carried out with
abrasives of relatively large grain size, it can nevertheless be de-
finitely stated that the usual method of polishing by rubbing with
fine emery paper is a most uneconomical procedure ; in fact, the use
of discs covered with emery paper results in a process of wear
frequently following an undue increase in temperature and oxidation
of the surface of the specimen. The speed at which the polishing
medium is applied is, as a general rule, far too great. There is no
gain in the speed of removal of material by revolving the disc at
high speed, except during the few initial seconds during which the
paper can be regarded as new. The coefficient of friction appears

to decrease with increasing pressure ; it also decreases with increasing polishing speed, but the decrease is slower. The frictional energy of course increases with increasing polishing speed whilst the specific polishing time diminishes in such a way that when the other conditions are constant the specific frictional energy (*i.e.*, the frictional energy required to remove 1 mg. per sq. cm. of metal) also remains constant. Owing to the rapid rate of removal of the polishing medium the specific frictional energy increases at a very high rate during the course of the polishing. The conclusion of Honda and Yamada that the rate of removal is proportional to the frictional energy only applies under certain very limited conditions, and, in particular, to only a single grade of polishing disc. In general it may be said that the present procedure for the preparation of metallographic specimens is exceedingly uneconomic, but, until improved methods are worked out, the method to be followed comprises that combination of pressure and speed which will complete the operation within a reasonable time without causing an undue rise in temperature or oxidation of the surface. The frictional energy must also be kept within reasonable limits in order to avoid any cold-work effect.

Magnetic Crack Detection. (Engineer, 1940, vol. 170, Sept. 20, pp. 191–192). Descriptions are given of two types of portable magnetic crack-detecting machines for examining ferrous materials. With one type of machine the principle employed is to magnetise the part slightly by supporting it between the poles of an electromagnet, the suspected crack being placed so that it is at right angles to the path of the magnetic flux. The part is then immersed in a fluid containing fine particles of iron and the crack is shown up by the particles lining up along the crack. With the other machine the part is magnetised by passing a heavy alternating current through it so that magnetism is only present along the actual crack. Various jigs and clamps are supplied with the machines, which can thus readily be adapted for testing parts of different length and shape.

Rail-Defect Detecting Car. (Engineering, 1940, vol. 150, Sept. 20, pp. 223–225). An illustrated technical description is given of one of the latest types of rail-defect detecting cars produced by Sperry Products Incorporated, Hoboken, New Jersey. This is one of several cars with which a total of 597,000 miles of track have been tested and over 304,000 defective rails detected in the period 1928–1940. Particulars of the electrical instruments and circuits are given and several types of the defects discovered are illustrated.

Some Properties of Alloy Equilibrium Diagrams Derived from the Principles of Lowest Free Energy. H. Lipson and A. C. Wilson. (Iron and Steel Institute, 1940, this Journal, Section I.). The purpose of this paper is to draw attention to the use of the principle of lowest free energy, as distinct from the phase rule, in the construction of equilibrium diagrams for binary and ternary alloy systems. Although free energies in themselves cannot be calculated,

the principle leads to certain results which can be used to check experimental work. Though these results are quoted in the literature on the subject, several diagrams have been found which contravene them, and it would thus appear that they are still not generally appreciated.

The principle of lowest free energy was first introduced into the subject by Roozeboom, who used it to derive all the forms of binary equilibrium diagrams. Also, using purely thermodynamic reasoning, he produced many important theorems concerning ternary equilibrium diagrams. The present paper shows, first, that the free-energy principle can be used to produce further detail in binary systems, and, secondly, that by applying it to ternary systems Roozeboom's theorems may be derived much more simply than by his original methods.

CORROSION OF IRON AND STEEL

The Corrosion of Mild and Copper-Bearing Steel Panels in Iron-Ore Wagons. L. Reeve. (Iron and Steel Institute, 1940, this Journal, Section I.). The losses in weight of a series of mild-steel and copper-bearing (copper, 0·38%) mild-steel test panels fitted in the end plates of three 21-ton steel iron-ore wagons have been compared over a period of nearly three years. The panels weighed approximately 40 lb. each, and were bolted into steel frames welded on to the end plates, so that each wagon carried a plate of each kind of steel. The panels were weighed at approximately six-monthly intervals after scrubbing with a dry wire-brush. The weight losses are tabulated and are shown graphically. The results indicate that at the end of approximately three years the average loss in weight of the copper-steel panels amounts to only 38% of that of the mild steel, and that it is getting relatively even smaller.

The loss in weight is due to a combination of corrosion and mild abrasion by the masses of iron ore. It is probable that the good result given by the copper-bearing steel is partly due to the fact that the scale on the latter is tightly adherent to the underlying plate, and exerts a certain amount of protective action upon it. There would appear to be little doubt of the economic value of using copper-bearing mild steels in the construction of wagons of the type described.

Cathodic Protection of Steel Water Tanks. E. E. Norman. (Journal of the American Water Works Association, 1940, vol. 32, July, pp. 1069–1074). The author discusses the theory, practical application and cost of cathodic corrosion control for steel water tanks. The equipment for this process of preventing the corrosion of steel tanks consists of one or more electrodes of stainless steel or graphite so fixed in the water and connected to a source of direct current supply that the whole forms a circuit in which the electrodes are anodes and the body of the tank is the cathode. The formation of hydrogen ions and calcium and other positive ions on the surface of the tank protects the steel from corrosive attack. The data relating to the cost of large installations for tanks of 350,000 and 750,000 gal. capacity show that both as regards capital and maintenance the electric process of protection is much more economical than painting.

Steel Tank Corrosion Prevention. W. C. Mabee. (Journal of the American Water Works Association, 1940, vol. 32, July, pp. 1075–1077). The author makes some observations from practical experience in the use of cathodic corrosion control for protecting the

interior surface of large steel water tanks. The principle on which this method is based is described in the preceding abstract. Tests made since the installation of the equipment in 1938 to a 1,500,000-gallon tank show satisfactory results, but precautions have to be taken to prevent damage to the electrodes by ice in the winter period.

Factors Which Influence External Corrosion of Tin Containers. K. G. Dykstra. (Sheet Metal Industries, 1940, vol. 14, Aug., pp. 839–842). The author points out some of the most common conditions responsible for the external corrosion of tin containers and suggests methods for their control. He classifies the types of corrosion as follows : (a) Corrosion attributable to general plant practices ; (b) corrosion due to unusual water conditions ; and (c) corrosion in the warehouse. To prevent the corrosion of tin containers during storage it is necessary to have a dry and properly sheltered storage space, uniformity of temperature and proper ventilation. The strict control of storage conditions is much more important in the storage of filled cans than it is for empty cans, because the former respond to temperature changes much more slowly than the latter, and there is therefore more condensation of moisture on the former.

Influence of Ferrite on the Intercrystalline Corrosion of Chromium-Nickel Austenitic Steels. (Metallurgist, 1940, vol. 13, Aug., pp. 124–127). It is well known that if certain chromium-nickel austenitic steels which are normally very resistant to corrosion are heated to a temperature in the range 500–900° C. they become susceptible to intercrystalline disintegration when subjected to chemical attack. In the present discussion a number of methods of eliminating or diminishing this effect are dealt with. From a survey of the results of several investigations of this subject it is seen that there is general agreement that intergranular attack of the chromium-nickel steels is occasioned by local impoverishment in chromium resulting from the precipitation of chromium carbide. The restoration of resistance to attack brought about by prolonged heating is thus due to diffusion of chromium in the austenitic steel again producing uniform distribution of chromium. The more rapid recovery of chromium-nickel steels containing ferrite is held to be due to the fact that the ferrite is initially richer in chromium and that diffusion of chromium occurs more readily in ferrite than in austenite. The effect of such additions as silicon, tungsten, molybdenum and vanadium is not confined to the influence they exert on ferrite formation. Each of them exercises a specific influence on the strength, welding properties, general corrosion and resistance to scaling.

Embrittlement Detector. Schroeder, Berk and O'Brien. (Mechanical Division of the Association of American Railroads : Combustion, 1940, vol. 12, Aug., pp. 19–21). After explaining the theory of the causes of caustic embrittlement in steel boiler plates, the authors describe a simple device which they have developed for

ascertaining whether a boiler water is liable to cause failure from this cause. The device consists of a special form of clamp which holds a test-piece of steel firmly to one of the tubes through which the boiler water is circulating ; an artificial leak is made in the tube which allows a minute quantity of the water to come in contact with the test-piece, and an adjusting screw through one end of the test-piece is set so as to exert a mechanical stress on the latter, at the same time opening a small space between the test-piece and the tube in which the boiler water can collect. The device is usually attached to a portion of tube fitted with isolation valves so that the test-piece can be removed and another fitted while the boiler is at full pressure. After a suitable period has elapsed the test-piece is removed and examined for intercrystalline corrosion or caustic embrittlement.

ANALYSIS

Estimation of Copper in High-Duty Cast Iron Containing Molybdenum. J. Stott. (Foundry Trade Journal, 1940, vol. 63, Aug. 22, p. 128). The author presents a method of making copper and molybdenum determinations when these elements are present together in high-duty cast iron. The method is as follows : 5 g. of the sample are dissolved in 100 ml. of 1 : 5 sulphuric acid, and when solution is complete the liquid is diluted to 300 ml. with water. The liquid is then brought to the boil and 10 g. of sodium thiosulphate are added carefully and the solution is boiled for 15 min. to expel the sulphur dioxide and to coagulate the precipitated mixed sulphides. The liquid is then filtered through a paper pulp pad, which is washed well with water saturated with hydrogen sulphide and acidulated with sulphuric acid. The pad and precipitate are transferred to a porcelain crucible and carefully ignited at approximately 550° C. The ignited precipitate is then transferred to a small beaker and dissolved in 10 ml. of hydrochloric acid, to which have been added a few drops of concentrated nitric acid. When solution is complete the liquid is diluted slightly and made ammoniacal, sufficient ammonia being added to hold the copper in solution. It is then boiled for 2 min. and filtered, washing well with 2% ammonia solution. The liquid is then diluted to 250 ml. and brought to the boil ; 15 ml. of a 2% solution of alpha-benzoin-oxime are added, and the solution is boiled for 2 min. Some paper pulp is added and the solution filtered; the precipitate is washed well with hot 2% ammonia solution, transferred to a crucible and ignited to copper oxide. This may be weighed as such, or dissolved in a minimum quantity of nitric acid, evaporated to low bulk, diluted with water, sodium carbonate solution added, and the precipitate dissolved in acetic acid, then boiled to expel carbon dioxide, cooled, potassium iodide added, and the liberated iodine titrated with sodium thiosulphate solution. The author states that satisfactory results have been obtained by this method on cast irons containing approximately 0·5% of copper and up to 1% of molybdenum.

Comparative Investigation of the Methods of Determining Iron and Ferrous and Ferric Oxides When Present Together. Z. E. Lukina. (Zavodskaya Laboratoriya, 1940, No. 1, pp. 18–22). (In Russian). The author compares three different methods of determining iron and ferrous and ferric oxides when present together. The methods were those of Kaufmann, of Ingeberg and the mercuric-chloride method. He concludes that the first two are suitable for

the analysis of iron ores and the products obtained from them by direct reduction, and that the mercuric-chloride method is suitable for determining metallic iron. Kaufmann's and Ingeberg's methods are equally accurate, but the latter takes longer. Preliminary tests on basic slag samples showed that the ferric oxide in it can be determined by Kaufmann's method, and the metallic iron and ferrous oxide by Ingeberg's method.

New Trend in the Practice of Determining Oxygen in Alloy Steels. G. Ya. Vaynberg. (Zavodskaya Laboratoriya, 1940, No. 1, pp. 23–25). (In Russian). The author's preliminary experiments in his investigation of methods of determining oxygen in alloy steels showed that all the metallic oxides which may be present in alloy steels can be completely, or almost completely, reduced with hydrogen at a temperature of 1250° C., heating being continued for at least $1\frac{1}{2}$ hr. The treatment was carried out in the presence of a " flux " consisting of a one-to-five mixture of tin and antimony in powder form. His subsequent experiments demonstrated that, to obtain consistent results, samples of the steel to be analysed should be massive and should have a regular geometrical shape, preferably cylindrical. This eliminates errors which may be caused by variable amounts of surface oxygen in the case of comminuted samples. A number of experiments showed the applicability of the method to low- and high-alloy steels.

Photo-Electric Determination of Phosphorus in Pig Iron and Iron Ore. A. Ya. Bursuk. (Zavodskaya Laboratoriya, 1940, No. 1, pp. 95–97). (In Russian). The method previously developed by the author (*see* Journ. I. and S.I., 1939, No. II., p. 241 A) for the determination of phosphorus in steels by reducing the phospho-molybdate complex with bivalent iron and sodium sulphite has now been applied to pig iron and iron ores. The preliminary treatment has been modified to deal with the appreciable amounts of silicon and carbon in pig iron and with the silica in iron ore. By this method, phosphorus can be determined in amounts up to 0.4% with an accuracy of 0.002–0.006% in pig iron, and 0.003–0.006% in ores.

Spectrochemical Analysis of Sheet Steel at the Great Lakes Steel Company. R. A. Sawyer and H. B. Vincent. (Journal of Applied Physics, 1940, vol. 11, July, pp. 452–458). The authors describe the spectrographic apparatus recently installed at the Ecorse Works, Michigan, of the Great Lakes Steel Corporation for making spectrographic analyses of specimens of deep-drawing-quality steel sheet. They also describe the procedure, which takes about 10–12 min., for the analysis of a single sample. The equipment is at present calibrated for determining chromium, copper, nickel and tin in the range of approximately 0.01–0.10%. Experience has proved that this apparatus permits determinations of the above elements in steel to be made with an accuracy of $\pm 0.001\%$ even when only 0.01% is present.

The Separation of Non-Metallic Inclusions from Cupola-Melted Cast Iron and the Determination of their Mineralogical Composition. B. S. Shvetsov, M. A. Matveev and Yu. P. Simanov. (Zavodskaya Laboratoriya, 1940, No. 2, pp. 219–223). (In Russian). As was to be expected, preliminary experiments to determine the nature of the non-metallic inclusions in cupola-melted iron confirmed that it is impossible to do this by taking Debye X-ray photographs. Experiments on the separation of non-metallic inclusions by dissolving the iron in hydrochloric acid, or by decomposing it with 20% copper sulphate solution, did not give satisfactory results, and the electrolytic method (as recommended by Scott), using a solution of magnesium iodide containing free iodine, was finally adopted. The optimum conditions for this method of separating the inclusions are described. The non-metallic inclusions separated in this fashion, some with, and some without a preliminary removal of the graphite by the heavy-liquid flotation method, were then subjected to X-ray and petrographic examination. In the X-ray diagrams of inclusions from various samples of cast iron of different compositions, lines corresponding to graphite, ferrous oxide, cementite, magnesium metasilicate, magnesium orthosilicate, montichellite, iron silicide and pyrites were found. Lines corresponding to hematite, quartz and corundum were also observed in samples from which the graphite had been removed by ignition in oxygen. The evidence suggests that some of the inclusions are present in a highly dispersed amorphous state. The petrographic examination did not give any positive results. Some chemical analyses of the non-metallic residues after removal of the graphite by oxidation are given.

Non-Metallic Inclusions in Steel. Quantitative Evaluation. Part I. W. H. Hatfield and G. W. Giles. (Iron and Steel Institute, 1940, this Journal, Section I.). The authors have sought to evaluate the different factors influencing methods of inclusion counting. Experimental evidence is given which indicates the importance of the magnification selected for observation purposes, and it is shown that when examining a number of steels of different characteristics, if the standard magnification for the examination is modified, then the relative order of cleanliness becomes different. It is also shown that the comparison charts at present extant have not the quantitative value which has hitherto been attributed to them.

It is shown that, whilst the conditions of polishing materially influence the inclusion count as determined by methods at present in vogue, a light etching tends to establish what appears to be a more reliable basis for comparison.

The authors conclude by expressing their view, resulting from their researches, that until solutions have been found for the present disabilities, the present methods of quantitative estimation of the degree to which steels are contaminated by non-metallic inclusions are impracticable.

Recommended Method for the Estimation of Slag Inclusions in Steel in Report No. 5 of the 19th Sectional Committee of the Japan Society for the Promotion of Scientific Research. K. Tawara. (Tetsu to Hagane, 1940, vol. 26, May 25, pp. 367–377). (In Japanese). The author explains the method of estimating the number of slag inclusions in steel drawn up by a committee appointed by the Japan Society for the Promotion of Scientific Research. The method is similar to that published by Jernkontoret, but in the one here described the inclusions are classified into one of two groups, *viz.*, those easily elongated by deformation of the steel surrounding them, and those remaining unchanged. A series of 40 micrographs, 80 mm. in dia., is used as a standard of comparison.

A Rapid Method for the Determination of Carbon in Coals. R. Belcher. (Fuel in Science and Practice, 1940, vol. 19, Aug., pp. 172–174). The high-temperature oxidation process which has been devised for the rapid determination of sulphur and chlorine in coals has been adapted for the determination of carbon in coals or other carbonaceous materials. The actual combustion process takes only 10 min., and a complete test can be made in half an hour. The coal is burnt in a stream of oxygen at a temperature of 1350° C., and the sulphur oxides and chlorine are absorbed in chromic-sulphuric acid, the water in anhydrone, and the carbon dioxide in soda-asbestos in a Midvale tube. The Midvale tube is swept out with air and, when cool, is weighed. The method has been compared with the standard Liebig method and gives accurate results for coals of all rank. It is considered that these rapid methods for the determination of sulphur, chlorine and carbon in coals are particularly useful for power-station engineers.

BOOK NOTICE

CAMP, J. M., and C. B. FRANCIS. *"The Making, Shaping and Treating of Steel."* By J. M. Camp and C. B. Francis. Re-written by C. B. Francis. Fifth Edition. 8vo, pp. xv + 1440. Illustrated. Pittsburgh, 1940 : Carnegie-Illinois Steel Corporation. (Price $7.50.)

This volume forms an excellent textbook of modern steelworks practice. Naturally the practice described is that of the United States, but the rapid exchange of ideas and methods among industrial countries in recent years has levelled out many of the local differences that previously existed, and the divergence between British and American plant and technique is now much less than it used to be.

There are four main divisions in the book, these being " The Making of Steel," " The Shaping of Steel," " The Composition and Heat Treatment of Steel " and " The Manufacture of Steel Wire, Sheet, Strip and Tubular Products." The description of steel-making processes follows standard lines, with chapters on the manufacture of pig iron and wrought iron, and others on the Bessemer, open-hearth and electric-steel processes. The information given in this section is well detailed and is supplemented by valuable photographs, diagrams and flow sheets. One minor criticism is that some of the drawings have been so reduced in reproduction that detail and the explanatory text are difficult to read. In each of the processes described both the theoretical and practical aspects of the operations are considered, and the reviewer was unable to find any notable omissions in the well-written presentation of the subject. Chapters on refractories, fuels, ores and fluxes, and slags are of very distinct value, and go far beyond a mere catalogue of types, compositions and properties, but the initial chapter of the book on some fundamental principles of chemistry and physics is, as can only be expected, totally inadequate either as an introduction to these sciences or as an aid to the better understanding of the rest of the book, and could be omitted without sensible loss.

The section on the shaping of steel deals in rather summary fashion with the foundry and the forge, and by comparison is generous in its treatment of the rolling mill. The rolling of steel is considered very fully, and the reviewer was pleased to note that accessory operations such as soaking, reheating and dressing were accorded the mention that their importance deserves. The design and general operation of rolling-mill equipment are described in one chapter, and the rolling of various semi- and fully-finished products is fully dealt with in the following text.

The treatment of steel is considered in conjunction with composition, and from elementary principles one is led rapidly to modern theory and practice, including grain-size control and the significance of the S-curve. The wide range of modern alloy steels is rather neatly covered by dividing these into two main classes : the pearlitic and the more highly alloyed austenitic and ferritic. Each of these in turn is split up into steels containing one alloying element and those containing more than one. By these means the authors have gone far to

present an unwieldy mass of information in a concise and easily comprehended manner. Tool steels are dealt with in a separate chapter.

The final section on the manufacture of wire, strip and tubes strikes one as being in the nature of an afterthought. Most of the information here could have been dealt with in the section on shaping, and one chapter on protective coatings might find its way without objection under the heading of treatment. This criticism is one of arrangement only, however, and the text in this part is on the same high level of usefulness as the remainder of the book.

As has been indicated, this work is comprehensive and up-to-date. Each chapter has its own bibliography of selected references and the indexing is good. The clear print and thin paper have enabled the 1440 pages to be contained in a book of only moderate size. Students of metallurgy in particular will profit by reading this book from cover to cover.

STEPHEN L. ROBERTON.

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SUBJECT INDEX.

[References to the papers read before the Institute are indicated by the word *Paper* following the page number. The letter *P*. denotes a reference in Section I. of the Journal which contains the reports of the proceedings of meetings, the papers read, and the discussions thereon. The letter *A*. denotes a reference to the section dealing with abstracts.

Indexing of Alloy Steels and Other Alloys. In the indexing of alloy steels, carbon and iron are ignored and the alloying elements contained in the steel are arranged in alphabetical order ; for example, all references to nickel-chromium-molybdenum steel will be found under the heading chromium-molybdenum-nickel steel. In the indexing of other alloys, carbon and iron, when present, are included in the title ; iron, when present, is always mentioned first and the other elements follow in alphabetical order, carbon being in all cases mentioned last. Examples : " Iron-silicon-carbon alloys " and " iron-chromium-nickel-carbon alloys."]

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